



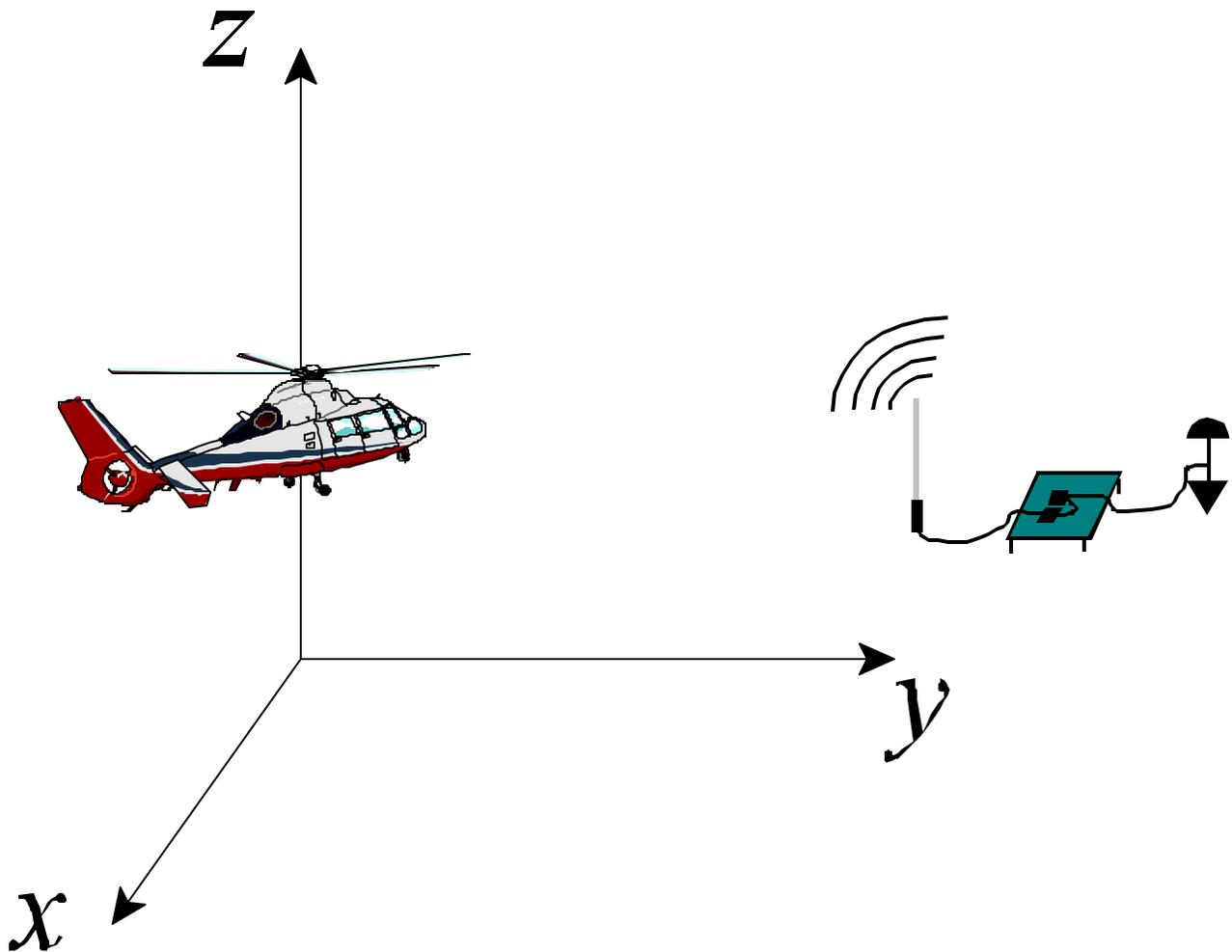
U.S. Department  
of Transportation  
**Federal Aviation  
Administration**

# **Volpe Center Acoustics Facility Time-Space-Position-Information System**

**Differential Global Positioning System  
User's Guide**

**Version 1.2**

**July 2000**



Prepared for:

U.S. Department of Transportation

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U.S. Department of Transportation

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This document is a user's guide for the Volpe Center Acoustics Facility's (VCAF) Time-Space-Position-Information (TSPI) System. The VCAF TSPI system is a differential global positioning system (dGPS) which may be utilized for highly accurate vehicle tracking during acoustic and other tests, as well as surveying of field measurement sites. Each section of the document is meant to be standalone in terms of its specific purpose. As such, portions of the document are redundant.

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Appendix F presents specifications for installation of GPS and communication antennae on aircraft.

When one initially enters the software, the following main window is displayed. All software functions described herein may be accessed through pull-down menus from the main window.





## **I. Base Station Multipath Test**

The purpose of a base station multipath test is to establish whether or not multipath affects reception of GPS satellite signals in the vicinity of the base station. It is important to perform this test during the hours of expected use of the Time-Space-Position-Information (TSPI) system (i.e., daylight hours, for most tests). See Appendix B for a more detailed discussion of GPS multipath issues. It is assumed that multipath is not an issue for the rover system.

### **A. Secure NovAtel GPS receiver and GLB Radio Antennae**



*The GPS antenna should be oriented with the north arrow on its base pointed north, such that it has a full view of the sky (i.e., in all directions). The altitude of the antenna should be such that any reflective objects in the vicinity, which may cause multipath problems, should be kept below the antenna. The GLB radio antenna should have a line-of-sight view to the aircraft at all times.*

### **B. Connect NovAtel GPS receiver (COM1) and Computer (serial port- COM1) via null modem cable**

### **C. Connect GPS Antenna to NovAtel GPS receiver**

### **D. Power up NovAtel GPS receiver (i.e., connect DC power cable between 12-V battery and receiver)**

### **E. Power up Computer**

### **F. Set Computer Time-Of-Day**

This is done so-that the time-of-day stamp for all data files may be referenced to the actual time-of-day.

### **G. Create data directory for storing all files (using either DOS or Windows Explorer)**

### **H. Invoke TSPI Software by running *TSPI.EXE***

### **I. Select Data Directory**

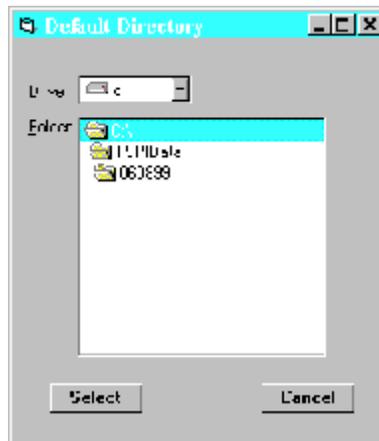
[File, Data Directory]



*The default data directory is the one previously used by the software.*

*However, this information is only saved when the program is closed down normally (i.e., it does not lock up).*

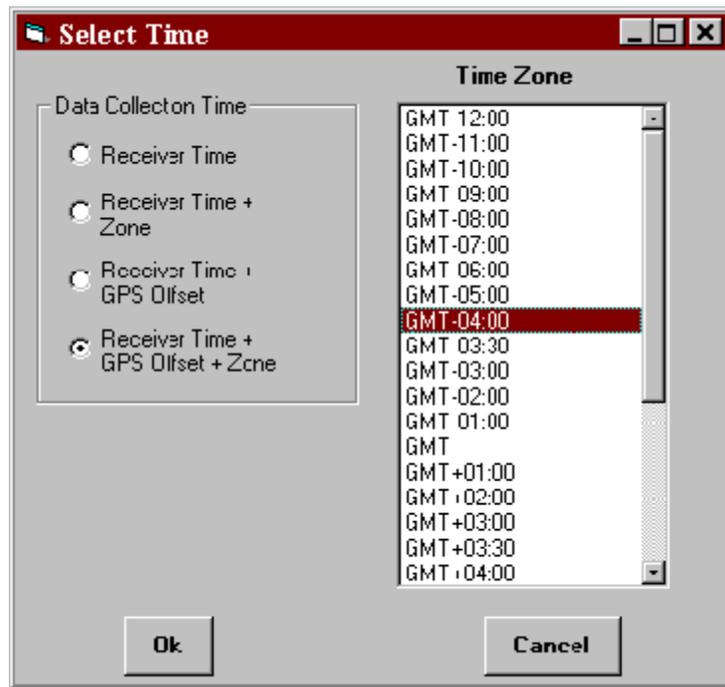
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J. Select Time-Base

[Options, Select Time]

“Receiver Time + GPS Offset + Zone” is the VCAF standard, where “GPS Offset” accounts for the 10+ second lag in GPS time with respect to UTC, and “Zone” is the relative difference between the local time and Greenwich Mean Time (GMT).



The following table presents the “Zone” offset for the four time zones within the continental United States:

<b>Time Zone</b>	<b>Daylight Savings Time</b>	<b>Standard Time</b>
Eastern	GMT - 0400	GMT - 0500
Central	GMT - 0500	GMT - 0600
Mountain	GMT - 0600	GMT - 0700
Pacific	GMT - 0700	GMT - 0800

This table is meant as quick-reference guidance for selecting the appropriate time zone offset, however, care should be taken to ensure time-of-day is correct- it should be verified once utilizing one of the base or rover functions.

K. Exit TSPI Software & Re-invoke

This is done so-that all settings entered above are saved. Settings may or may not be preserved unless this step is performed.

- L. Perform multipath test  
[Base, Multipath Test]



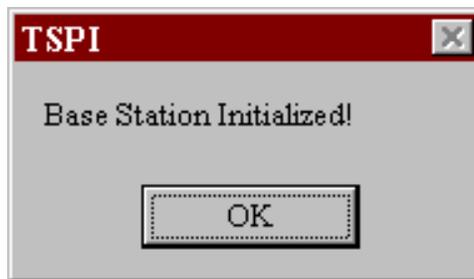
*The multipath test is hardwired to run for 24 hours. To run for shorter time periods, simply exit out of the program.*



*The NovAtel GPS receiver must have satellite lock, indicated by an illuminated green "Valid Position" light on the front panel, prior to this step-if it does not, run-time error '11' may occur (see Section VIII for more info on error messages).*

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A dialog box stating “Testing PC to NovAtel Connection” should appear, followed by two more dialog boxes, one after the other:



The two windows on the following page will automatically be opened. The first (main) window provides a real-time summary of the multipath data being collected. The second window, which may be reached by minimizing the first, shows the real-time streaming data from the tracked satellites.

- M. After the multipath testing, further analysis of the resultant data files is required (i.e., with a spreadsheet) to determine if multipath is an issue at the measurement site (see Appendix B for a more detailed discussion of the multipath analysis.) Note: The TSPI software rejects all satellites below an elevation angle of 10 degrees to help minimize multipath effects at the base station.

GPS seconds into week = 405799      Offset = 13      Nominal Time = 12:43:0E												
Channel	Prn	Pseudorange	Sigma	Carrier Phase	Sigma	Dopp	C/No	Lock Time	Status	Az	FI	Reject Code
Channel 1	17	24275563.133	0.246	-1.27568532.392	0.012	3.37.855	41.6	195.71	F04	298.31	16.66	0
Channel 2	26	22.54415.623	0.18	-1.6421392.394	0.009	3477.695	44.3	187.92	E27	88.99	31.82	0
Channel 3	8	24436033.934	0.261	-1.28411334.398	0.011	1871.739	41	112.89	E34	84.85	11.55	0
Channel 4	4	24387024.913	0.309	-1.2815354.318	0.012	-3019.741	39.6	174.14	E44	11.57	13.62	0
Channel 5	6	21585267.801	0.174	1.3430937.152	0.005	1098.623	43.2	191.53	E54	288.58	47.04	0
Channel 6	27	24865974.367	0.606	-1.3083270.104	0.03	696.555	33.9	182.5	E64	83.45	11.86	0
Channel 7	10	20531109.039	0.09	-1.07890462.164	0.005	-1233.327	51.3	195.76	E94	33.64	17.92	0
Channel 8	24	21534004.103	0.125	-1.3161707.772	0.003	-1906.333	47.4	107.95	E44	82.37	45.19	0
Channel 9	13	21743693.132	0.172	-1.4264438.329	0.003	-1536.05	43.3	193.11	E84	64.2	47.76	0
Channel 10												
Channel 11												
Channel 12												

```

1. 1L9128341.48C,1003.873.043.47.07.667.4JE/4,13,22/L715.526.0.180,115326936.010,0.011.623.95J.44.2.71
$SA,A,1,017,4C1523.00,0.8,13,44.09,17.06,-5.755,0.30,3C8.C5,22.17,-12.252,C,4.45.77.62.16,16.170,C,5.273.36.36.0
40.C5,-7.049.0*2F
$RGEA,1017,0.524,03.8,0001.DCFE,16.23951490.7111.C.29E,-125380692/61.0.C12,-3473.316,1C.2.174.538.E14,3C
4991.39E,1.00R,-1191.596.47.4.1170.140.F34.5.22283855.9F3,11.9R,-1.71.71536.106.0.0F8,-684.837.45.5.1.75.540.F
6,1L912795C.3A,1003.877.713.45.71.67.4JE/4,13,22/L7057.34.0.187,1153263421.98,0.010.622.994.43.9.71,
$SA,A,1,017,4C1524.00,0.8,13,44.09,17.05,-5.57.0.30,3C8.C5,22.18,-12.258,C,4.45.78.62.16,16.416,C,5.273.36.36.0
40.C5,-7.029.0*2F
    
```



## **II. Base Station Position Averaging**

The purpose of base station position averaging is to, in lieu of a known, surveyed marker, accurately determine the absolute location of the base station. This step may be abbreviated if a simple, relative coordinate system is all that is required.

### **A. Secure NovAtel GPS receiver Antenna**



*The GPS antenna should be oriented with the north arrow on its base pointed north, such that it has a full view of the sky (i.e., in all directions). The altitude of the antenna should be such that any reflective objects in the vicinity, which may cause multipath problems, should be kept below the antenna.*

### **B. Connect NovAtel GPS receiver (COM1) and Computer (serial port- COM1) via null modem cable**

### **C. Connect GPS Antenna to NovAtel GPS receiver**

### **D. Power up NovAtel GPS receiver (i.e., connect DC power cable between 12-V battery and receiver)**

### **E. Power up Computer**

### **F. Set Computer Time-Of-Day**

This is done so-that the time-of-day stamp for all data files may be referenced to the actual time-of-day.

### **G. Create data directory for storing all files (using either DOS or Windows Explorer)**

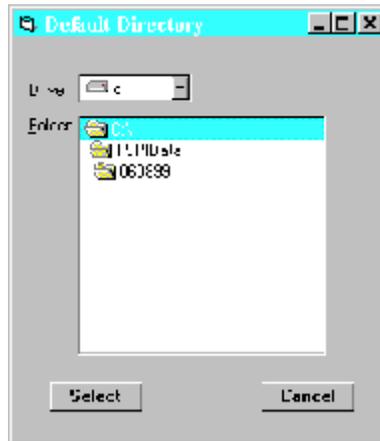
### **H. Invoke TSPI Software by running *TSPI.EXE***

### **I. Select Data Directory**

[File, Data Directory]



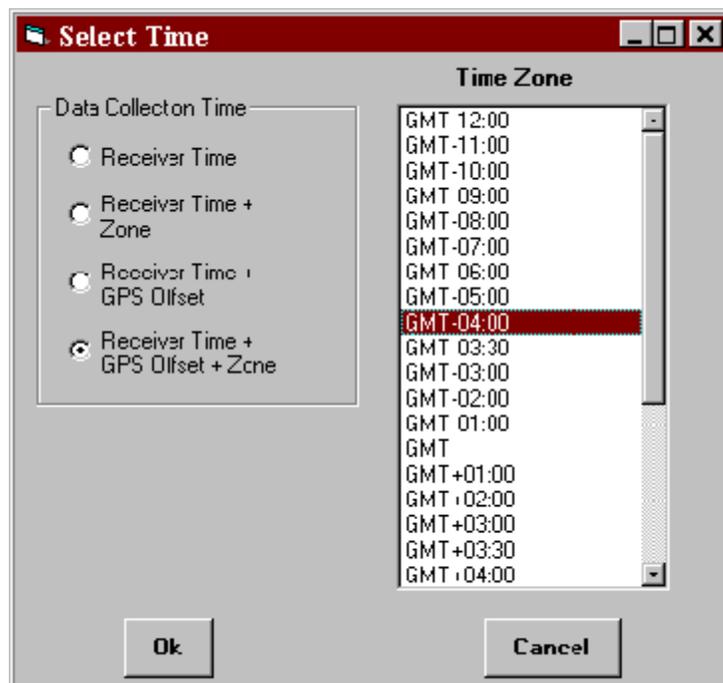
*The default data directory is the one previously used by the software. However, this information is only saved when the program is closed down normally (i.e., it does not lock up).*



J. Select Time-Base

[Options, Select Time]

“Receiver Time + GPS Offset + Zone” is the VCAF standard, where “GPS Offset” accounts for the 10+ second lag in GPS time with respect to UTC, and “Zone” is the relative difference between the local time and Greenwich Mean Time (GMT)



The following table presents the “Zone” offset for the four time zones within the continental United States:

<b>Time Zone</b>	<b>Daylight Savings Time</b>	<b>Standard Time</b>
Eastern	GMT - 0400	GMT - 0500
Central	GMT - 0500	GMT - 0600
Mountain	GMT - 0600	GMT - 0700
Pacific	GMT - 0700	GMT - 0800

This table is meant as quick-reference guidance for selecting the appropriate time zone offset, however, care should be taken to ensure time-of-day is correct- it should be verified once utilizing one of the base or rover functions.

- K. Perform a long-term averaging to determine the base station position

[Base, Survey Base Station]



*This should normally be done over a 24-hour period. With a 24-hr duration, a 1-hr update rate would be ideal. As time progresses, the GPS receiver will converge on the actual position of the base station. For tests where absolute position is not required, a 2-minute duration with a 30-second update rate will suffice.*



*The NovAtel GPS receiver must have satellite lock, indicated by an illuminated green “Valid Position” light on the front panel, prior to this step- if it does not, run-time error ‘11’ may occur (see Section VIII for more info on error messages).*

A dialogbox stating “Testing PC to NovAtel Connection” should appear, followed by an initialization box:



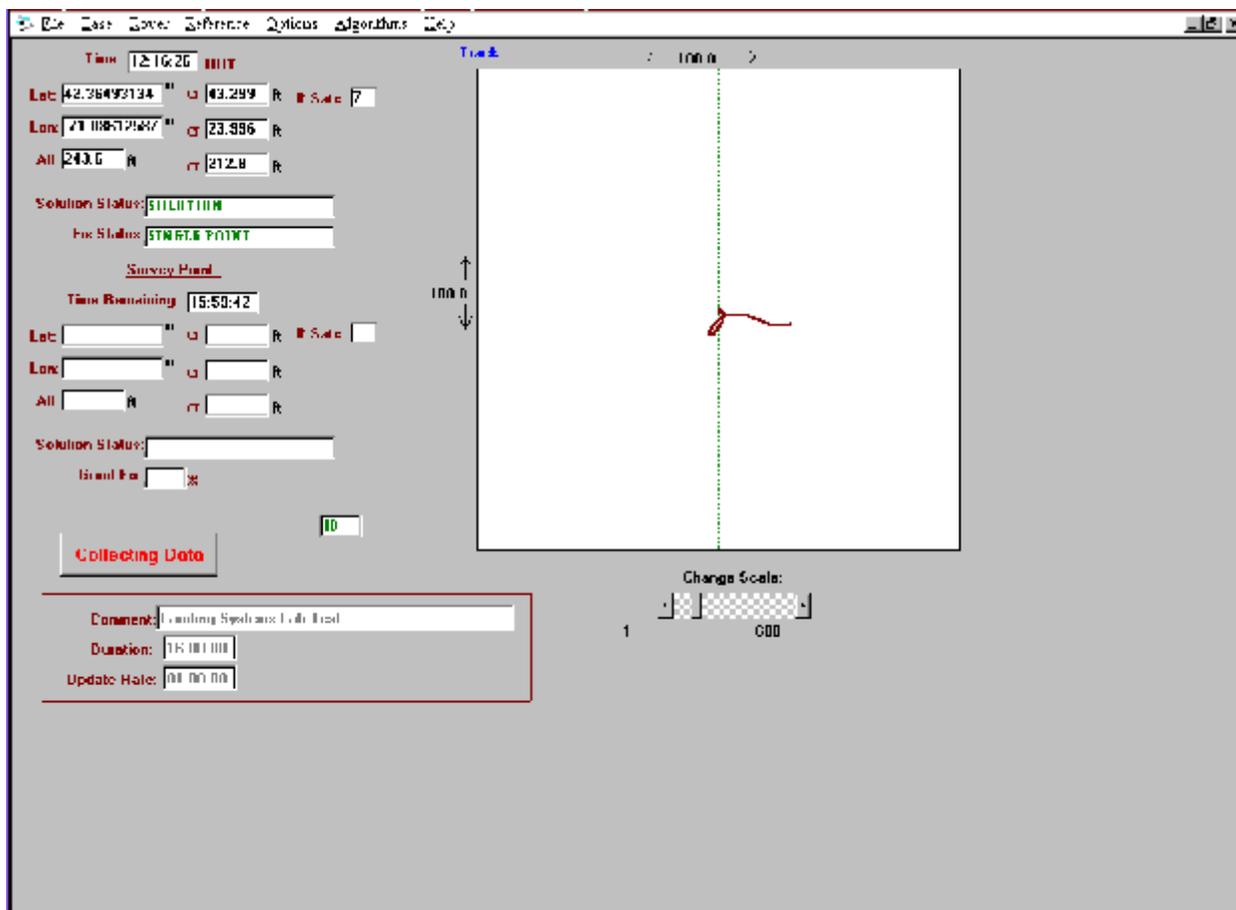
After the NovAtel GPS Receiver is initialized, the Survey Base Station dialog box appears.

Collect position data for the base station antenna. Enter "Comment", i.e., location and other unique site information; "Duration"; "Update Rate" and click on the "Begin Survey" button. During data collection, this button switches to "Collecting Data". At the end of data collection, it switches to "Survey Complete".



*The data in the "Survey Point" box will not appear until after the duration of one averaging period. Subsequently, the data in this box represents the average from the previous "Update Rate" period. The small box to the right of the data collection button indicates in real time the number of seconds into any given averaging period.*

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After “Survey Complete” appears on the data collection button, transcribe final data for the base station survey from the appropriate SB data file (i.e., write down coordinates in degrees and altitude in feet).



### III. Deploying the Base Station

The base station is deployed to transmit differential corrections to the rover, typically installed on an aircraft for a flight test, or positioned at a survey location.



*If the base station is being deployed immediately after either the "Base Station Multipath Test" (Section I) or "Base Station Position Averaging" (Section II), briefly power down the NovAtel GPS receiver so-that it loses its initialization and exit out of the TSPI software before continuing (see Section VIII-A for guidance on software error messages).*

- A. Connect NovAtel GPS receiver (COM1) and Computer (serial port- COM1) via null modem cable
- B. Secure NovAtel GPS receiver and GLB Radio Antennae



*The GPS antenna should be oriented with the north arrow on its base pointed north, such that it has a full view of the sky (i.e., in all directions). The altitude of the antenna should be such that any reflective objects in the vicinity, which may cause multipath problems, should be kept below the antenna. The GLB radio antenna should have a line-of-sight view to the aircraft at all times.*

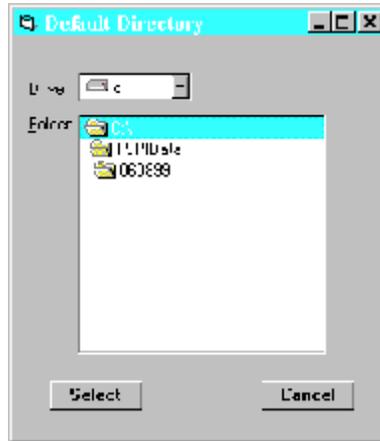
- C. Connect GPS Antenna to NovAtel GPS receiver
- D. Power up NovAtel GPS receiver (i.e., connect DC power cable between 12-V battery and receiver)
- E. Power up Computer
- F. Set Computer Time-Of-Day  
This is done so-that the time-of-day stamp for all data files may be referenced to the actual time-of-day.
- G. Create data directory for storing all files (using either DOS or Windows Explorer)
- H. Invoke TSPI Software by running *TSPI.EXE*
- I. Select Data Directory

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[File, Data Directory]



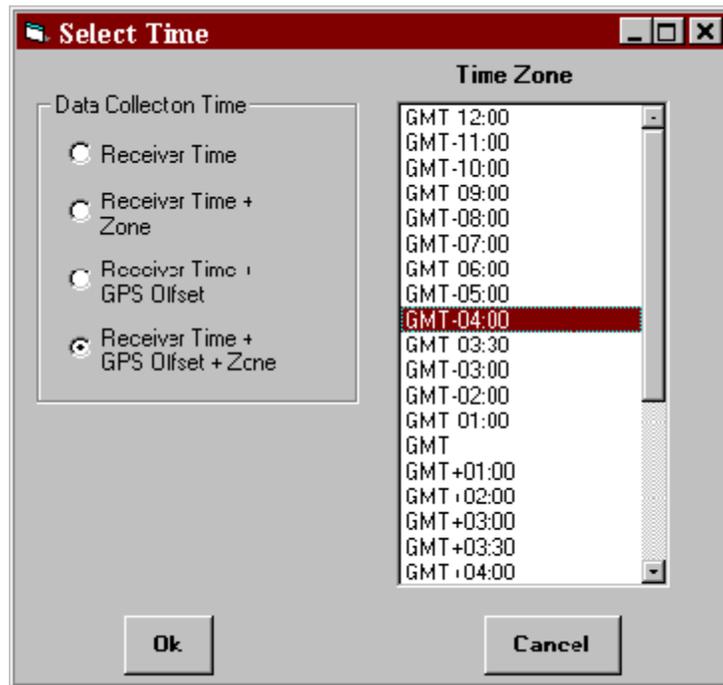
*The default data directory is the one previously used by the software. However, this information is only saved when the program is closed down normally (i.e., it does not lock up).*



J. Select Time-Base

[Options, Select Time]

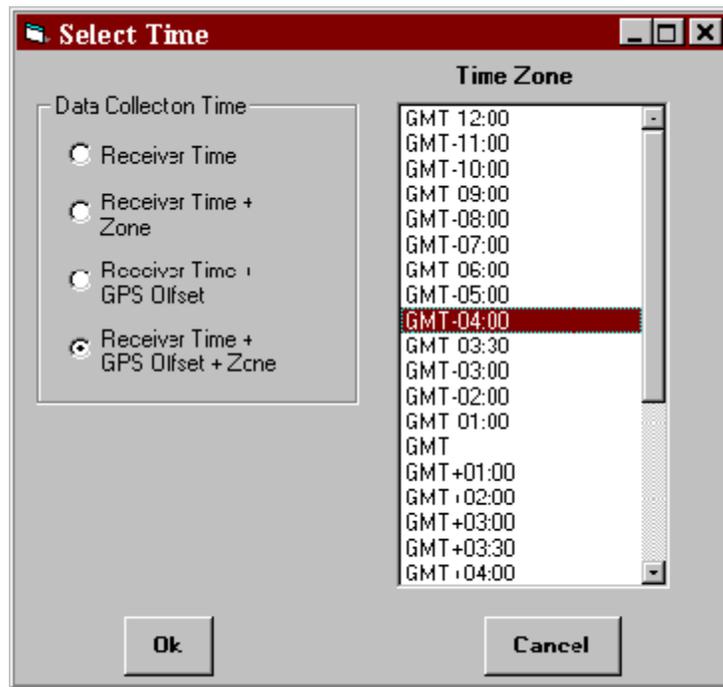
“Receiver Time + GPS Offset + Zone” is the VCAF standard, where “GPS Offset” accounts for the 10+ second lag in GPS time with respect to UTC, and “Zone” is the relative difference between the local time and Greenwich Mean Time (GMT)



The following table presents the “Zone” offset for the four time zones within the continental United States:

<b>Time Zone</b>	<b>Daylight Savings Time</b>	<b>Standard Time</b>
Eastern	GMT - 0400	GMT - 0500
Central	GMT - 0500	GMT - 0600
Mountain	GMT - 0600	GMT - 0700
Pacific	GMT - 0700	GMT - 0800

This table is meant as quick-reference guidance for selecting the appropriate time zone offset, however, care should be taken to ensure time-of-day is correct- it should be verified once utilizing one of the base or rover functions.

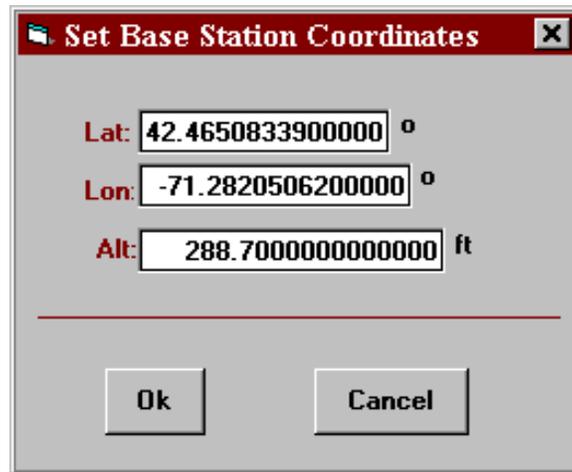


K. Enter Base Station Location Coordinates  
[Reference, Base Station Position]

These coordinates should come from either a known, surveyed location, or from the position averaging as in Section II. Any value may be used if a simple, relative coordinate system is all that is required.



*When using the coordinates from an averaging period of the Base Station Positioning Averaging (Section II), it is necessary to cut and paste the values from the resultant "Sbmmddy.xxx" file, as opposed to simply reading them from the dialog box, as there is more precision in the data file.*



- L. Exit TSPI Software & Re-invoke  
This is done so-that all settings entered above are saved. In the case that the software and/or the computer lock up, settings may or may not be preserved.
- M. Check base station coordinates, time base, and data directory to ensure all information was saved
- N. Turn On Base Station  
[Base, Turn On Base Station]



*The NovAtel GPS receiver must have satellite lock, indicated by an illuminated green "Valid Position" light on the front panel, prior to this step- if it does not, run-time error '11' may occur (see Section VIII for more info on error messages).*

A dialog box stating "Testing PC to NovAtel Connection" should appear, followed by two more dialog boxes, one after the other:





Click "OK"

- O. Connect Radio Antenna to GLB Radio
- P. Power Up GLB Radio
- Q. Connect GLB Radio (25-pin connection) to NovAtel GPS receiver (Com2) via serial cable
- R. Check GLB Radio Transmission  
The TX LED on the GLB radio display panel should flash once-per-second - this indicates transmission of differential corrections (see Section VIII, Helpful Hints, for more insight on the GLB Radio LEDs).
- S. Disconnect Computer from NovAtel GPS receiver



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*After initialization of the base station, extreme care should be taken in making or breaking connections to the NovAtel GPS receiver. If power is lost on the receiver, however briefly, the initialization may be lost.*  
-----

Note: The software rejects all satellites below an elevation angle of 10 degrees to help minimize multipath effects at the base station.

#### **IV. Deploying the Rover**

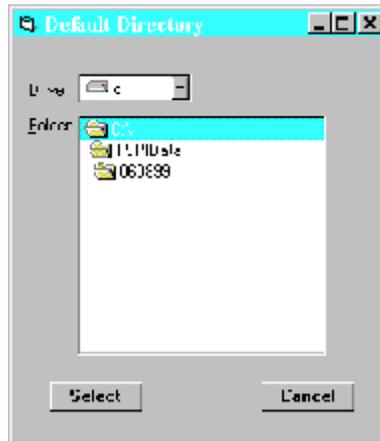


*If rover is being deployed immediately after any of the base station software features are used, briefly power down the NovAtel GPS receiver (rover) so-that it loses its initialization and exit out of TSPI software before continuing (see Section VIII-A for guidance on software error messages).*

- A. Secure NovAtel GPS receiver and GLB Radio Antennae
- B. Connect NovAtel GPS receiver (COM1) and Computer (serial port- COM1) via null modem cable
- C. Connect GPS Antenna to NovAtel GPS receiver
- D. Power up NovAtel GPS receiver (i.e., connect DC power cable between 12-V battery and receiver)
- E. Set Computer Time-Of-Day  
This is done so-that the time-of-day stamp for all data files may be referenced to the actual time-of-day.
- F. Create data directory for storing all files (using either DOS or Windows Explorer)
- G. Invoke TSPI Software by running *TSPI.EXE*
- H. Select Data Directory  
[File, Data Directory]



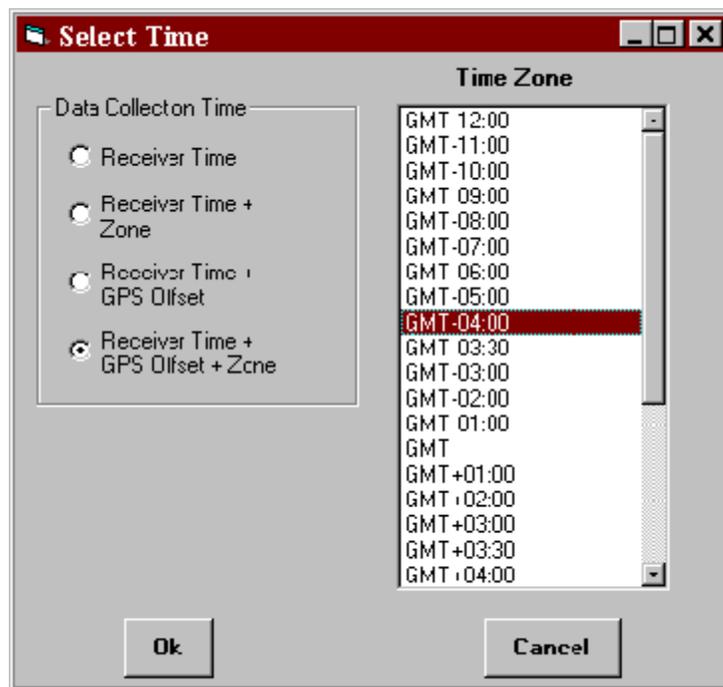
*The default data directory is the one previously used by the software. However, this information is only saved when the program is closed down normally (i.e., it does not lock up).*



I. Select Time-Base

[Options, Select Time]

“Receiver Time + GPS Offset + Zone” is the VCAF standard, where “GPS Offset” accounts for the 10+ second lag in GPS time with respect to UTC, and “Zone” is the relative difference between the local time and Greenwich Mean Time (GMT).



The following table presents the “Zone” offset for the four time zones within the continental United States:

<b>Time Zone</b>	<b>Daylight Savings Time</b>	<b>Standard Time</b>
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Mountain	GMT - 0600	GMT - 0700
Pacific	GMT - 0700	GMT - 0800

This table is meant as quick-reference guidance for selecting the appropriate time zone offset, however, care should be taken to ensure time-of-day is correct- it should be verified once utilizing one of the base or rover functions.

J. Surveying 2 Points to Define Local Coordinate System

J.1 Prepare to Survey Two Points to Determine Local Coordinate System

- If only absolute position (latitude/longitude) is being used (i.e., no local X-Y-Z coordinate system is needed), step I is not necessary.*
- The first of the two points will be the origin of the coordinate system. The second will be a point on the positive x-axis.*
- The NovAtel GPS receiver must have satellite lock, indicated by an illuminated green “Valid Position” light on the front panel, prior to this step- if it does not, run-time error ‘11’ may occur (see Section VIII for more info on error messages).*

[Rover, Survey Points]

A dialog box stating “Testing PC to NovAtel Connection” will appear followed by:



- J.2 After initialization of NovAtel GPS Receiver, connect radio antenna to GLB Radio
- J.3 Power Up GLB Radio
- J.4 Check GLB Radio Reception  
The RX LED on the GLB Radio should flash once-per-second - this indicates reception of differential corrections (see Section VIII, Helpful Hints, for more insight on the GLB Radio LEDs).
- J.5 Connect GLB Radio (25-pin connection) to NovAtel GPS receiver (Com2) via serial cable
- J.6 Locate GPS Antenna at Point to be Surveyed
- J.7 Collect Data

Enter "Comment", i.e., location and other unique site information; "Duration" and collect data (typically 1 to 2 minutes) by clicking on the "Survey Point" button. During data collection, this button switches to "Collecting Data". At the end of data collection, it switches to "Survey Point". Transcribe final data for the first point and then repeat this procedure for the second survey point (i.e., write down coordinates in degrees and altitude in feet).



*The data in the "Survey Point" box will not appear until the completion of data collection.*

---

K. Define the Local Coordinate System

[Reference, Rover Coordinate System]

Copy transcribed position data for two survey points into the appropriate fields.

Axis Origin:	Point on the X Axis:
Lat: 42.3623033400000 °	Lat: 42.3627617300000 °
Lon: -70.9707050400000 °	Lon: -70.9767037000000 °
Alt: -209.9970000000000 ft	Alt: -213.2750000000000 ft
Z Delta: 0 ft	Z Delta: 0 ft

The “Z Delta” field is used for taking into account two things: (1) the height of the antenna used for the surveying ( $Z_1$ ) above ground level; and/or (2) a relative difference in ground height between the two survey points used to define the local coordinate system ( $Z_2$ ). As an example, given a  $Z_1$  of -5 ft. (i.e., a survey antenna on a 5-ft. tripod) and a  $Z_2$  of -2 ft. (i.e., the x-axis survey point 2 ft. lower in altitude than the origin survey point), “Z Delta” for the origin would be -5 and “Z Delta” for the x-axis point would be -7.



It is important to take into account any relative difference in height between the two survey points to ensure the z-axis is truly vertical. For example, an aircraft that flies directly over the origin should pass through a point with coordinates  $x=0, y=0$  (see figure below).

**Note that as of TSPI Version 1.2, the Z Delta function does not function properly. Its discussion in this section is included simply for illustrative purposes.**

L. Exit TSPI Software & Re-invoke

This is done so-that all settings entered above are saved. In the case that the software and/or the computer lock up, settings may or may not be preserved- this should be checked, but it likely will save time re-entering data in the case of a lock-up.

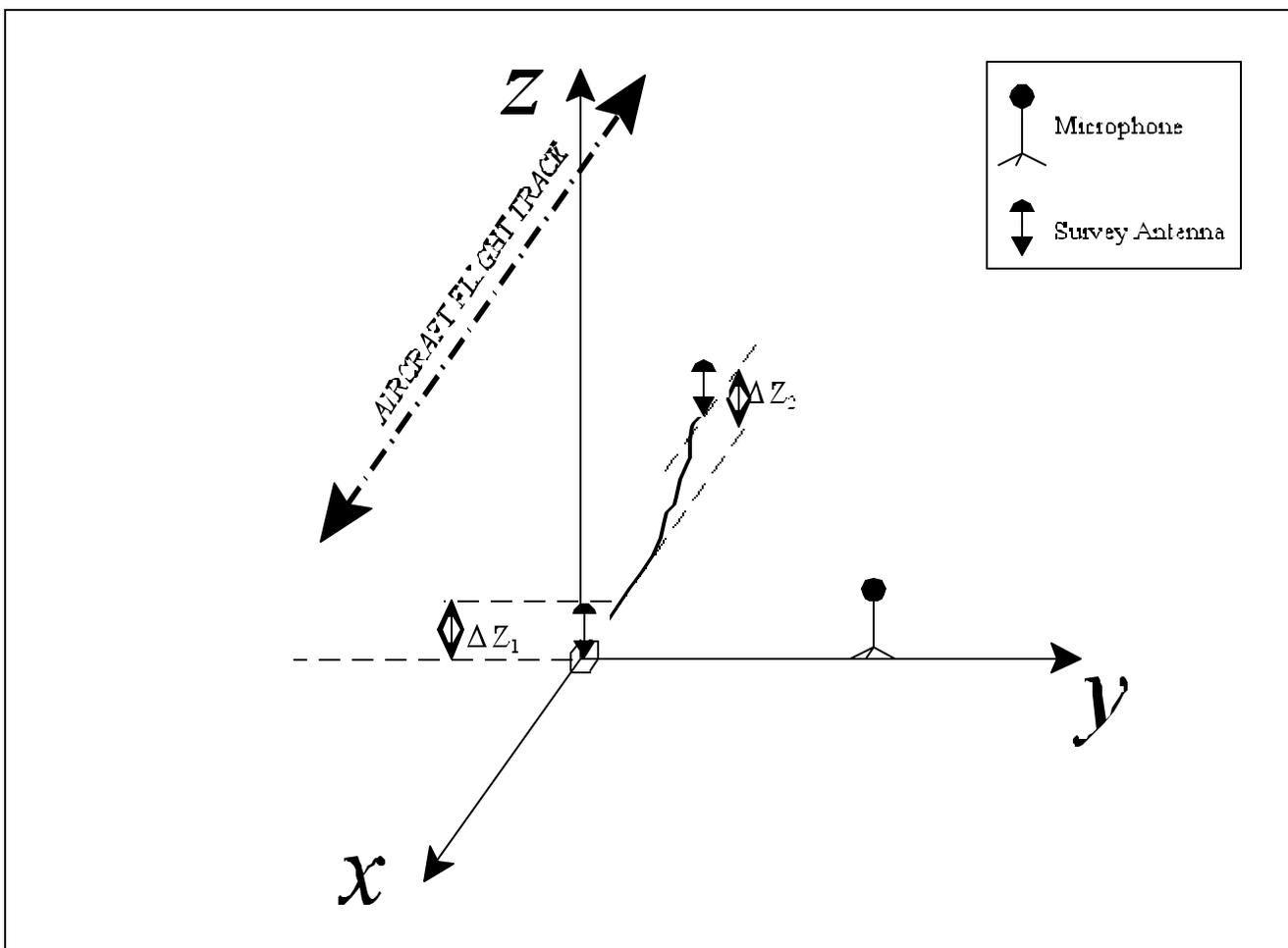
M. Check All Settings

N. Prepare to Collect Tracking Data

[Rover, Collect Track Data]

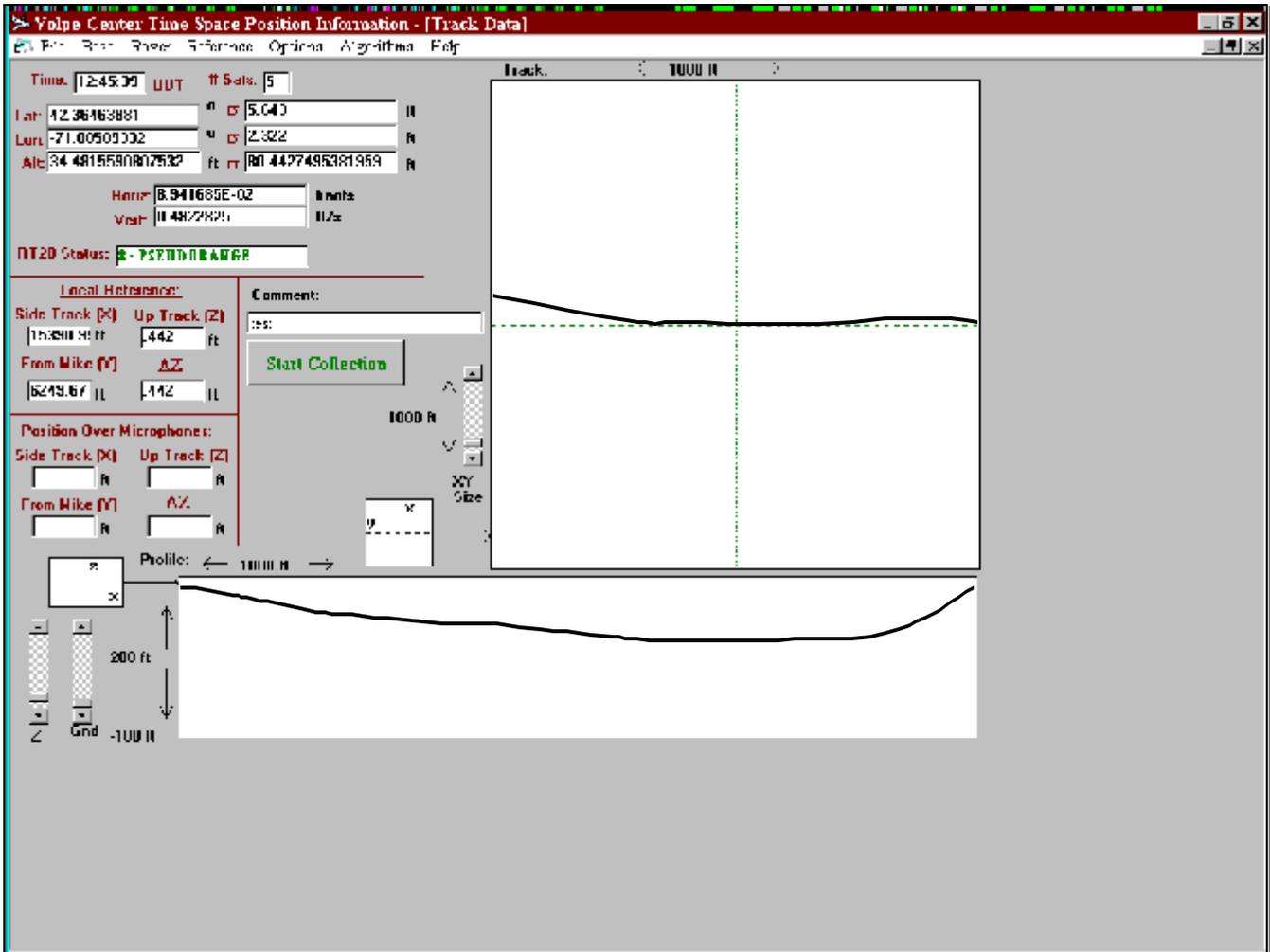


The NovAtel GPS receiver must have satellite lock, indicated by an illuminated green "Valid Position" light on the front panel, prior to this step- if it does not, run-time error '11' may occur (see Section VIII for more info on error messages).



TSPI software will initialize the NovAtel GPS receiver. The differential solution will only be "pseudorange" (8) at this point, since corrections are not being received. The following is

the main window used for collecting track data:



- O. Power Up GLB Radio
- P. Check GLB Radio Reception  
The RX LED on the GLB Radio should flash once-per-second - this indicates reception of differential corrections.
- Q. Connect GLB Radio (25-pin connection) to NovAtel GPS receiver (Com2) via serial cable



---

If the NovAtel GPS receiver is receiving the corrections, the RT20 solution status (indicated in the “Solution Status” box) should converge to 2, 1, and then finally to 0, given optimum conditions. If the system does not converge to either a 0 or 1, something is wrong with the system.

RT20 Solution Status	System Accuracy
0	20 cm
1	30 cm
2	variable
8	100 m (No Differential)

- R. Click “Start Collection” to collect event-based tracking data  
Enter Comment (i.e., Event number and/or other event-specific data).  
The “Start Collection” button will now read “Stop File *xxx*”, where ‘*xxx*’ is the TD file extension and automatically increments each time data collection is initiated (see Section V, Output File Formats, for more information about output data files).



Prior to collecting actual position data (in the case of a flight test) or survey data (in the case of a site survey), one should check the orientation of the coordinate system. Survey two locations, including one of the two points used to define the coordinate system, as well as one point *not* on the x-axis. Experience shows that detailed site diagrams, including compass directions and local topographical features, aide in the interpretation of TSPI data after-the-fact.

---



```

Volpe Center TSPI (Version 1.20) Multipath Data
06/27/00, Units - Feet, Time - Seconds + 228 Offset + Time Base
09 40 36, 23704703 3', 134 4213514856,-124564331 847, 36, 465, 659 537,-23703579 7645545, 02, 27 31,554 ,0010075, 315 64, 19 74,-3 536, 0
09 40 37, 23700171 309, 134 009717400312, 124564010 375, 35 9, 477, 150 411, 23700700 2752025, 02, 27 31,554 ,0010075, 315 64, 19 05, 0 359, 0
09 40 38, 23703740 388, 134 02287892097,-124563321 236, 36, 473, 658 418,-23703607 424283, 02, 27 31,554 ,0010075, 315 64, 19 05,-3 382, 0
09 40 39, 23703210 365, 134 01612014795,-124562657 307, 36 3, 455, 653 065,-23703476 2453392, 02, 27 31,554 ,0010075, 315 64, 19 06,-3 13, 0
09 40 40, 23703480 406, 134 174630871252,-124561953 437, 36 3, 455, 654 25,-23703347 113369, 02, 27 31,554 ,0010075, 315 64, 19 06,-3 087, 0
09 40 41, 23703749 385, 134 863351750755,-124561255 755, 35 9, 473, 658 537,-23703216 1495482, 02, 27 31,554 ,0010075, 315 64, 19 07,-3 273, 0
09 40 42, 23703710 374, 134 003071000201, 124560674 071, 36 3, 447, 654 70, 23703075 107001, 02, 27 31,554 ,0010075, 315 64, 19 07, 0 272, 0
09 40 43, 23700104 309, 134 005007900407, 124560014 12, 37, 491, 712 155, 23702950 130142, 02, 27 31,554 ,0010075, 315 64, 19 07, 0 272, 0
09 40 44, 23703749 385, 134 33291302661,-124560515 1582, 37 1, 415, 713 301,-23702821 88188, 02, 27 31,554 ,0010075, 315 64, 19 09,-3 178, 0
09 40 45, 23702111 036, 134 877757802605,-124559471 538, 37, 419, 712 155,-23702675 1562422, 02, 27 31,554 ,0010075, 315 64, 19 09,-3 219, 0
09 40 46, 23702571 302, 134 781056681207,-124559773 81, 36 3, 427, 713 654,-23702537 9095033, 02, 27 31,554 ,0010075, 315 64, 19 09,-3 287, 0
09 40 47, 23702538 171, 134 181674 27797,-124558979 705, 36 3, 421, 710 8,-23702397 953558, 02, 27 31,554 ,0010075, 315 64, 19 1,-3 15, 0
    
```

**B. Survey Base Data**

Survey Base data files are output during the procedures outlined in Section II of this document. They contain data pertaining to the absolute position of the dGPS base station. A new file (with associated incremented file extension) is created each time this function is invoked.

Filename Format: [SBmmddyy.xxx] (“mm”=month; “dd”=day; “yy”=year; “xxx”=file increment)

**Data Fields:**

- 3-line Header: 1<sup>st</sup> line: “Volpe Center TSPI (Version 1.20) Survey Base Data”
- 2<sup>nd</sup> line: Comment Field (entered during data collection)
- 3<sup>rd</sup> line: Data Collection Specifics: Date/Units/Duration/Update Rate/Time Base

**Data Records: Time-of-Day;**

- Average Position: Latitude (°); Latitude Standard Deviation(°); Longitude (°); Longitude Standard Deviation (°); Altitude (ft); Altitude Standard Deviation(ft); Number of Seconds into Average; Seconds per Sample
- RT20 Solution Status (beginning of survey to current time): Mean; Maximum; Minimum
- Number of Satellites (current record): Mean; Maximum; Minimum
- Instantaneous Position: Latitude (°); Latitude Standard Deviation(°); Longitude (°); Longitude Standard Deviation (°); Altitude (ft); Altitude Standard Deviation(ft); Number of Seconds into Average; Seconds per Sample

The following is an example of a “Survey Base” data file:

```

Volpe Center TSPI (Version 1.20) Survey Base Data
06/27/00, Units - Feet, Time - Seconds + 228 Offset + Time Base
09 40 36, 23704703 3', 134 4213514856,-124564331 847, 36, 465, 659 537,-23703579 7645545, 02, 27 31,554 ,0010075, 315 64, 19 74,-3 536, 0
09 40 37, 23700171 309, 134 009717400312, 124564010 375, 35 9, 477, 150 411, 23700700 2752025, 02, 27 31,554 ,0010075, 315 64, 19 05, 0 359, 0
09 40 38, 23703740 388, 134 02287892097,-124563321 236, 36, 473, 658 418,-23703607 424283, 02, 27 31,554 ,0010075, 315 64, 19 05,-3 382, 0
09 40 39, 23703210 365, 134 01612014795,-124562657 307, 36 3, 455, 653 065,-23703476 2453392, 02, 27 31,554 ,0010075, 315 64, 19 06,-3 13, 0
09 40 40, 23703480 406, 134 174630871252,-124561953 437, 36 3, 455, 654 25,-23703347 113369, 02, 27 31,554 ,0010075, 315 64, 19 06,-3 087, 0
09 40 41, 23703749 385, 134 863351750755,-124561255 755, 35 9, 473, 658 537,-23703216 1495482, 02, 27 31,554 ,0010075, 315 64, 19 07,-3 273, 0
09 40 42, 23703710 374, 134 003071000201, 124560674 071, 36 3, 447, 654 70, 23703075 107001, 02, 27 31,554 ,0010075, 315 64, 19 07, 0 272, 0
09 40 43, 23700104 309, 134 005007900407, 124560014 12, 37, 491, 712 155, 23702950 130142, 02, 27 31,554 ,0010075, 315 64, 19 07, 0 272, 0
09 40 44, 23703749 385, 134 33291302661,-124560515 1582, 37 1, 415, 713 301,-23702821 88188, 02, 27 31,554 ,0010075, 315 64, 19 09,-3 178, 0
09 40 45, 23702111 036, 134 877757802605,-124559471 538, 37, 419, 712 155,-23702675 1562422, 02, 27 31,554 ,0010075, 315 64, 19 09,-3 219, 0
09 40 46, 23702571 302, 134 781056681207,-124559773 81, 36 3, 427, 713 654,-23702537 9095033, 02, 27 31,554 ,0010075, 315 64, 19 09,-3 287, 0
09 40 47, 23702538 171, 134 181674 27797,-124558979 705, 36 3, 421, 710 8,-23702397 953558, 02, 27 31,554 ,0010075, 315 64, 19 1,-3 15, 0
    
```

---

C. Survey Point Data

Survey Point data files are output during the procedures outlined in Section II-K of this document. They contain data pertaining to the absolute position of the points surveyed to define a local coordinate system. A new file (with associated incremented file extension) is created each time this function is invoked. If, however, multiple data points are collected without closing the TSPI software, the separate data points will appear as individual lines within the same data file.

Filename Format: [SPmmddyy.xxx] (“mm”=month; “dd”=day; “yy”=year; “xxx”=file increment)

Data Fields:

1<sup>st</sup> line Header: 1<sup>st</sup> line: Type of Data (Survey Point)/Date/Units/Time Base

Data Records: Comment Field; Time-of-Day; Duration; RT20 Status; Latitude (°); Latitude Standard Deviation(°); Longitude (°); Longitude Standard Deviation (°); Altitude (ft); Altitude Standard Deviation(ft)

The following is an example of a “Survey Point” data file:

```
Volpe Center TSPI (Version 1.20) Survey Point Data, 06/27/00, Units - Feet, Time - Receiver + GPS Offset + Time Base  
Comment: Axis Origin: Intersection of walkway & track, 10:00:34,00:02:00,0,42.3004743431667,0.1202700,71.1303635007000,0.2177625,55.6533,0.6070677  
Comment: Axis: Intersection of walkway & track, 10:11:01,00:02:00,0,42.3883536837916,0.165417E-02,-71.1382561347916,0.1856125,55.10484,0.4497749
```

D. Track Data

Track Data data files are output during the procedures outlined in Section IV-N of this document. They contain data collected: (1) during surveying of positions after a local coordinate system is established, and (2) during flight tests. Two types of track data files are generated by the TSPI software: Track Position [TP] and Track Velocity [TV].

Track Position Data Files

Filename Format: [TPmmddyy.xxx](“mm”=month; “dd”=day; “yy”=year; “xxx”=file increment)

Data Fields:

6-line Header: 1<sup>st</sup> line: “Volpe Center TSPI (Version 1.20) Aircraft Track Position Data”, Date

2<sup>nd</sup> line: Comment Field (entered during data collection)

3<sup>rd</sup> line: “(P)osition at 2 Hz”

4<sup>th</sup> line: Units; Time Base

---





The following is an example of a "Track Data- Velocity" data file:

```
Volpe Center TSPI (Version 1.20) Aircraft Track Velocity Data, 06/27/00
Event # 342, Microphone 3R Sanity Check
(V)elocity at 2 seconds
Units = Feet, Time = Receiver + GPS Offset + Time Zone
Reference: Origin (x,y,z,offset z) 42.3884743431667, -71.1383695007083, 55.6539, 0
Reference: X Axis (x,y,z,offset z) 42.3883536837916, -71.1382561347916, 55.10484, 0
10:32:31,5.831534E-03,6.561667E-03
10:32:33,7.775378E-03,-3.280833E-02
10:32:35,1.166307E-02,-0.0295275
10:32:37,9.719222E-03,-3.280834E-03
10:32:39,7.775378E-03,0
```





The following diagram is an example of a printed solution when one selects "Print Solution".

```

CROSS PLUMBL = -1.1E3000000000000000E-11 FC
YLONG PLUMBL = 3321.332200000000 FC
COMBLTED PLUMBL COORDINATES:

QB      = 1.01E081130000000 FC
NOCLR  = -3000.32112010123 FC
EVAL   = 1038.18140413011 FC
COMBLTED NOCLR-BOJNCTUD EVALS COORDINATES:

BL      = 2110243.0231011
YL      = 10418144.3521032
BL      = 2511335.0021011
YL      = 50880011.0244000
CL      = 14133005.1842412
BL      = 0.13010000000000000
VL      = 12403303.4082000
YJBR0   = 3.2043033331832 reqdms
EVAL    = 30021400.021201 FC
CONJUGATE:

YJF     = -103.00000000000000 FC
YON     = -10.014400000000000 reqdms
YFC     = 43.003118200000000 reqdms
X AXTE BOJNF:

YJF     = -300.30240000000000 FC
YON     = -10.001130200000000 reqdms
YFC     = 43.310834430000000 reqdms
OJDFNF:

```

## **VII. System Components**

This section presents a current list of system components. Where appropriate, current component model numbers are highlighted after the item in “[ ]” with serial numbers in italics.

### **Base Station**

GPS receiver (L1) [NovAtel 3151R] *CGN94340121*  
Data-link radio [GLB SNTR 150] *712136*  
Laptop computer [IBM Thinkpad 770] *78-CY580*  
GPS antenna with choke ring (L1/L2) [NovAtel GPS-503]  
Communication antenna [Antenex FG1360]  
9-pin to 25-pin serial cable  
9-pin to 9-pin null-modem serial cable  
TNC GPS antenna cable  
BNC communication antenna cable  
two tripods  
threaded rod for mounting GPS antenna  
miscellaneous clamps/adapters for mounting antennae  
Innovative International AC-to-DC converter [SB115A] (powers data-link radio off of AC current)  
Compass (for orienting base station receiver and drawing site diagram)  
100'+ tape measure

### **Rover** (*Deployed in either a “survey” mode or on an aircraft for tracking data*)

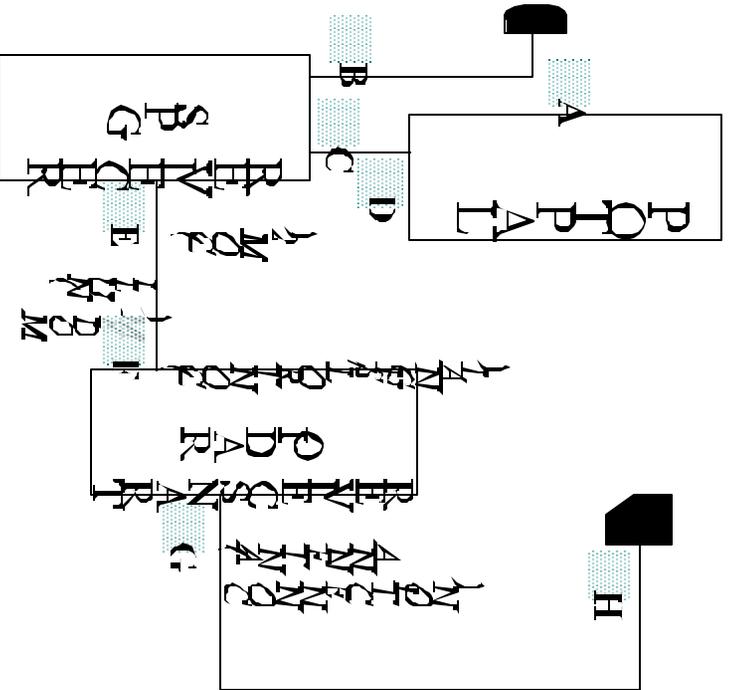
GPS receiver (L1) [NovAtel RT20E] *CGK97360001*  
Data-link radio [GLB SNTR 150] *712137*  
Laptop computer [IBM Thinkpad 770]  
GPS antenna [NovAtel GPS-501 (survey mode, L1); GPS-511 (aircraft mode, L1); GPS-512 (aircraft mode, L1/L2)]  
Communication antenna [Dorne & Margolin C63-1/A (straight, 20" clearance); C63-2 (bent, 8" clearance)]  
9-pin to 25-pin serial cable  
9-pin to 9-pin null-modem serial cable  
TNC GPS antenna cable  
BNC communication antenna cable  
miscellaneous clamps/adapters for mounting antennae

*TSPI.EXE* software  
Current Version: 1.20, Dated 4/24/2000

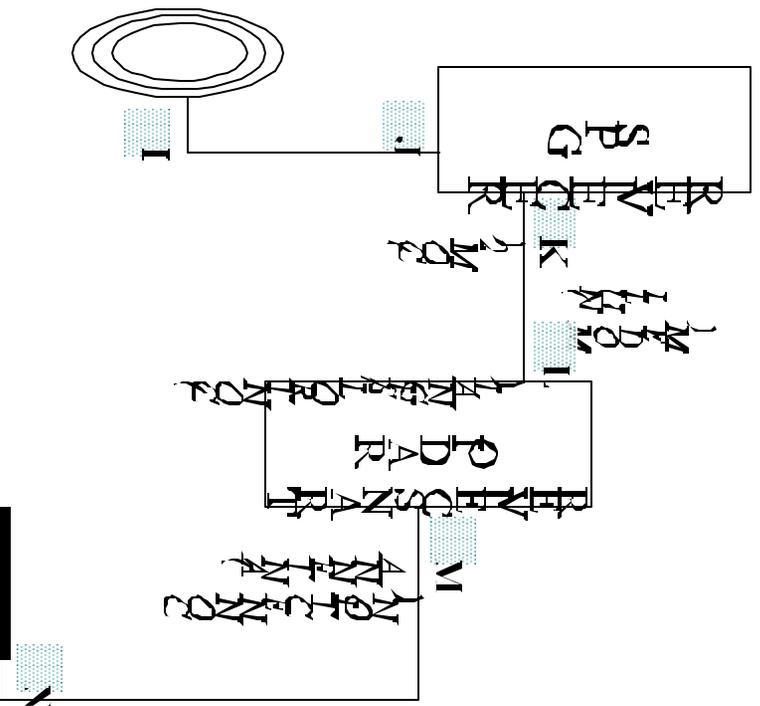
The figure on the following page presents the interconnection of the various pieces of instrumentation within the VCAF TSPI system, as arranged for final deployment (i.e., for collection of real-time tracking data).

The MVP Defined with Respect to

EVOR



NOTES AND



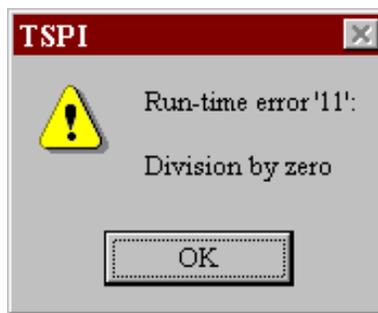
## VIII. Helpful Hints

This section provides the user with some guidance with respect to system errors and performance.

### A. Error Messages

#### A.1 Run-time Error 11

The following error may occur when one attempts to initialize the NovAtel GPS receiver prior to achieving satellite lock:



*Possible Solution:* Wait for satellite lock and re-try.

#### A.2 COM port of laptop computer not connected properly to NovAtel GPS receiver

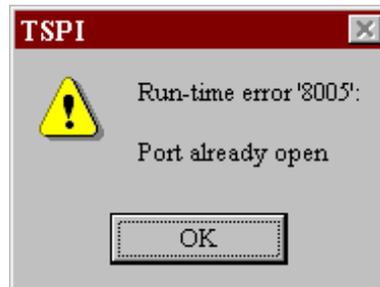


*Possible Solutions:* Check connection of null modem cable at both ends.  
Ensure serial port of computer is set to COM1, *not* COM2, etc.

#### A.3 Run-time Error 8005

The following error may occur if one attempts to utilize rover functions in the TSPI software after

already using base station functions, without first closing out of the software and re-initializing (or vice-versa).



*Possible Solution:* Close out of TSPI software and re-invoke.

**B. Power Connections**

**DO NOT** power up the GLB Radio without either the antenna or another load connected to the antenna connection.

All power connections for NovAtel GPS receiver, GLB Radio and any invertors should be first made at the gel-cell end, and then at the actual unit.

**C. Data Files**

The TSPI software automatically increments the file extension when multiple data files of a single type are collected, beginning with "000".

**D. System Accuracy**

RT20 Solution Status	System Accuracy
0	20 cm
1	30 cm
2	variable
8	100 m (No Differential)

**E. System Crashes**

It is recommended that the VCAF TSPI software be closed and reinvoked when switching between base station and rover functions, as it is known to crash when this is done in a single session (i.e., without closing out of the software).

F. GLB Radio LED

Step	LEDs Illuminated	
	Base Station	Rover
Power up Radio	PR, CS	PR, CS
Connect Radio to NovAtel	RS TX (flashes 1/second)	RS RX (flashes 1/second)



## **IX. Planned Future Enhancements to TSPI Software and Manual**

This section presents a list of planned future enhancements/changes to the TSPI software.

- A. Ability to enter either an x-axis *or* y-axis point for defining a local coordinate system.
- B. Ability to enter either an x-axis *or* y-axis shift when defining local coordinate system (i.e., if one of the two points is at the center of an active runway, and cannot therefore practically be surveyed).
- C. Correct ) Z functionality for defining coordinate system.
- D. Integrate multipath test and base station position averaging functions.
- E. Add “# of Satellites” box in Survey Base.
- F. Add appendix to manual including procedures and discussion associated with site surveying.
- G. Add FAR36-type visual tolerances for approach\takeoff\level flyover operations.
- H. Enable analysis of PDOP during Survey functions.
- I. Compile TSPI Software using Visual Basic Version 6 (currently version 5 is used).



**Appendix A:**

**Coordinate Conversion from Geodetic (Lat-Lon) to Measurement Frame (X-Y)**

## OBJECTIVE

The objective of this appendix is to present equations which convert geodetic position data (i.e., latitude, longitude, and altitude) derived from a GPS receiver on board an aircraft to rectangular coordinates associated with a measurement program. Both exact and approximate equations are presented.

## MATHEMATICAL PRELIMINARIES

### Earth Datum Model

The WGS-84 model for the earth is an oblate ellipsoid with semi-major axis  $a$  given by

$$a = 6,378,137.0 \text{ m} \quad \text{Eq. 1}$$

Distance  $a$  is converted to English units using 39.37 in./m, the appropriate conversion factor for geodetic survey applications. The result is

$$a = 20,925,604.5 \text{ ft (US Survey)} \quad \text{Eq. 2}$$

The semi-minor axis  $b$  is not defined. Instead the flattening  $f$  is specified as

$$f = \frac{a - b}{a} = \frac{1}{298.257,223,563} \quad \text{Eq. 3}$$

### Earth Parameters Used for Calculations

For computational formulas, the eccentricity  $e$  (actually the square of the eccentricity  $e^2$ ) is used rather than the flattening,

$$e^2 = 1 - \left(\frac{b}{a}\right)^2 = 2f - f^2 = 0.006694379990141317 \quad \text{Eq. 4}$$

Instead of the semi-major axis, computational formulas employ the “radius of curvature in the prime vertical”  $r_p = r_p(L)$

$$r_p = r_p(L) = \frac{a}{\sqrt{1 - e^2 \sin^2(L)}} \quad \text{Eq. 5}$$

Here  $L$  is the latitude of the location involved. Note that  $r_p$  is not constant, but instead varies with location (e.g., the radius of curvature is different at the aircraft and reference point locations); the notation  $r_p(L)$  is intended to reinforce the fact that  $r_p$  is a function of  $L$ .

### Reference Points and Aircraft Geodetic Positions

Two reference points (or waypoints) are used. The first (and main) reference point is the origin for measurement program coordinate system. It has latitude  $L_0$ , longitude  $\mathcal{S}_0$ , and altitude  $h_0$ , all relative to the WGS-84 ellipsoid. The second reference point is used to define the azimuth direction of the measurement program local coordinate frame. It has latitude  $L_1$ , longitude  $\mathcal{S}_1$ , and altitude  $h_1$ .

The aircraft has latitude  $L_a$ , longitude  $\mathcal{S}_a$ , and altitude  $h_a$ .

### EXACT EQUATIONS

#### Positions in Earth-Centered Earth-Fixed (ECEF) Frame

The earth-centered earth-fixed (ECEF) frame, with axes  $x$ ,  $y$  and  $z$ , is defined as follows:

- $x$  lies in plane of the equator, positive sense points 90 deg east of the Greenwich meridian
- $y$  coincides with spin axis, positive sense points toward north pole
- $z$  lies in plane of the equator, positive sense points toward the Greenwich meridian

Vectors coordinatized in the ECEF frame have a superscript  $e$ .

The position of first reference point (waypoint), expressed in the ECEF frame, is

$$\mathbf{P}_0^e = \begin{bmatrix} P_{0x} \\ P_{0y} \\ P_{0z} \end{bmatrix} = \begin{bmatrix} [r_p(L_0) + h_0] \cos L_0 \sin \lambda_0 \\ [(1 - e^2)r_p(L_0) + h_0] \sin L_0 \\ [r_p(L_0) + h_0] \cos L_0 \cos \lambda_0 \end{bmatrix} \quad \text{Eq. 6}$$

The aircraft position expressed in the ECEF frame is

$$P'_a = \begin{bmatrix} P_{ax} \\ P_{ay} \\ P_{az} \end{bmatrix} = \begin{bmatrix} [r_p(L_a) + h_a] \cos L_a \sin \lambda_a \\ [(1 - e^2)r_p(L_a) + h_a] \sin L_a \\ [r_p(L_a) + h_a] \cos L_a \cos \lambda_a \end{bmatrix} \tag{Eq. 7}$$

Observe that the two radii of curvature,  $r_p(L_0)$  and  $r_p(L_a)$ , are, in general, not equal because they correspond to different latitudes. The difference vector

$$\Delta P' = P'_a - P'_0 = \begin{bmatrix} \Delta P_x \\ \Delta P_y \\ \Delta P_z \end{bmatrix} = \begin{bmatrix} P_{ax} - P_{0x} \\ P_{ay} - P_{0y} \\ P_{az} - P_{0z} \end{bmatrix} \tag{Eq. 8}$$

is the position of the aircraft relative to the first reference point in the ECEF frame.

**North-Pointing Frame**

The north-pointing frame is level (that is, has two axes which are tangent to the WGS-84 ellipsoid) at the latitude and longitude of the first reference point. Its coordinate axes are: East,  $E$ ; North,  $N$ ; and Up,  $U$ .

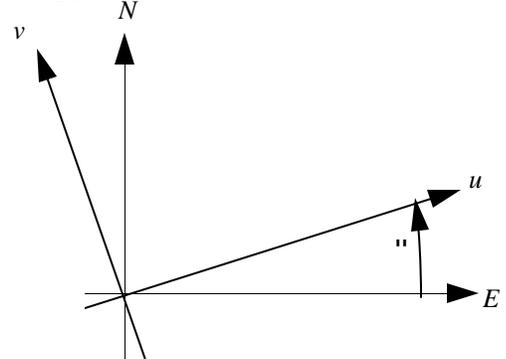
The position of the aircraft relative to the first reference point, coordinatized in the north-pointing frame is

$$\begin{bmatrix} \Delta P_E \\ \Delta P_N \\ \Delta P_U \end{bmatrix} = \begin{bmatrix} \cos \lambda_0 & 0 & -\sin \lambda_0 \\ -\sin L_0 \sin \lambda_0 & \cos L_0 & -\sin L_0 \cos \lambda_0 \\ \cos L_0 \sin \lambda_0 & \sin L_0 & \cos L_0 \cos \lambda_0 \end{bmatrix} \begin{bmatrix} \Delta P_x \\ \Delta P_y \\ \Delta P_z \end{bmatrix} \tag{Eq. 9}$$

Observe that the 3x3 matrix in Eq. 9 is constant for a given test program; thus these trigonometric functions need not be computed in real time.

**Measurement Program Frame**

The measurement program frame has its origin at the latitude and longitude of the first reference point. Its coordinate axes are  $u$ ,  $v$  and  $w$ .



Axis  $u$  is level, and its positive sense points toward the second reference point. It is expected that, in most applications,  $u$  will be the along-runway axis. Angle  $\alpha$  is subtended by axes  $E$  and  $u$  and is positive when  $u$  is north of  $E$  (see figure). Axis  $v$  is also level; it is orthogonal to  $u$  with positive sense  $\pi/2$  radians counterclockwise from  $u$ . In most applications,  $v$  will be the cross-runway axis. Axis  $w$  is vertical (same as  $U$ ).

When angle  $\alpha$  is known, the position of the aircraft relative to the first reference point, coordinatized in the measurement program frame, is given by

$$\begin{bmatrix} \Delta p_u \\ \Delta p_v \\ \Delta p_w \end{bmatrix} = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \Delta p_E \\ \Delta p_N \\ \Delta p_U \end{bmatrix} = \begin{bmatrix} \Delta p_E \cos\alpha + \Delta p_N \sin\alpha \\ -\Delta p_E \sin\alpha + \Delta p_N \cos\alpha \\ \Delta p_U \end{bmatrix} \quad \text{Eq. 10}$$

To find angle  $\alpha$ , use Eqs. 6-9, with the exception that, in Eq. 7, the latitude  $L_1$  and longitude  $\lambda_1$  of the second reference point are used in place of those for the aircraft. Denote the result from Eq. 9 by

$$\begin{bmatrix} \Delta p'_E \\ \Delta p'_N \\ \Delta p'_U \end{bmatrix} \quad \text{Eq. 11}$$

Then  $\alpha$  is given by

$$\alpha = \arctan(\Delta p'_N, \Delta p'_E) \quad \text{Eq. 12}$$

where the two-argument arctan function has arguments (opposite\_side, adjacent\_side).

Note that  $\alpha$  is constant for a given test program. Thus, in Eq. 10, the sin/cos terms are also constant and do not have to be computed in real time.

### APPROXIMATE EQUATIONS

The equations below were derived from the exact equations by expanding all trigonometric (sin/cos) expressions in Taylor series about the first reference point. As a result, the trigonometric functions in Eq. 7 do not have to be computed in real-time; only addition and multiplication are done in real time to implement this technique. Numerical testing has revealed that in the Taylor series expansion, terms up to and including second-order must be retained in

---

order to reduce the approximation error to less than 1 ft for an aircraft within 15 mi of the first reference point.

In place of Eqs. 6-9, the expression for each coordinate in the north-pointing frame is computed from a sum of products, where each product is a constant ( $A$ ,  $B$ , etc.) times the difference between the aircraft and first reference point latitude, longitude, and/or altitude. Latitudes and longitudes which are “free standing” (i.e., not the argument of a trigonometric function) must be expressed in radians.

$$\begin{aligned}\Delta P_E &= A_E(\lambda_a - \lambda_0) + B_E h_a(\lambda_a - \lambda_0) - C_E(L_a - L_0)(\lambda_a - \lambda_0) \\ A_E &= r_p(L_0) \cos(L_0) \\ B_E &= \cos(L_0) \\ C_E &= r_p(L_0) \sin(L_0)\end{aligned}\tag{Eq. 13}$$

$$\begin{aligned}\Delta P_N &= A_N(L_a - L_0) + h_a(L_a - L_0) + B_N(\lambda_a - \lambda_0)^2 \\ A_N &= r_p(L_0) [1 - e^2 \cos^2(L_0)] \\ B_N &= \frac{1}{4} r_p(L_0) \sin(2L_0)\end{aligned}\tag{Eq. 14}$$

$$\begin{aligned}\Delta P_U &= (h_a - h_0) - A_U(L_a - L_0)^2 - B_U(\lambda_a - \lambda_0)^2 \\ A_U &= \frac{1}{2} r_p(L_0) \\ B_U &= \frac{1}{2} r_p(L_0) \cos^2(L_0)\end{aligned}\tag{Eq. 15}$$

As is the case for the exact equations,  $r_p(L_0)$  denotes the radius of curvature for the first waypoint. Also as for the exact method, Eq. 10 is used to find the aircraft position in the measurement frame from its East-North-Up coordinates.

**Appendix B:**

**System Flight Test: 7/15/99**

## B.1 Introduction

Described herein is a flight test of the Volpe Center Acoustics Facility (VCAF) Differential Global Positioning System (dGPS) Time-Space-Position-Information (TSPI) system. The test was performed by the Acoustics Facility at Fitchburg Municipal Airport on July 15, 1999. The flight test was the culmination of a series of tests of both the software and hardware over an approximate one-year development period. The objective of the test was to determine the dynamic performance of the system (specifically, accuracy and reliability) installed on an aircraft operating under conditions considered typical of those encountered in aircraft noise certification. Version 1.1 of the TSPI software (dated 5/29/99) was used for the flight test.

About 50 miles west of Boston, Fitchburg Municipal Airport is located in Fitchburg, MA. For the tests, the differential base station was placed on the airport control tower (currently unused). The electronics were housed within the top floor control room, while the GPS and communication antennae were both placed on the roof of the building. The following figure illustrates the set-up of the base station electronics.



The following figure illustrates the location of the base station GPS and communication antennae.



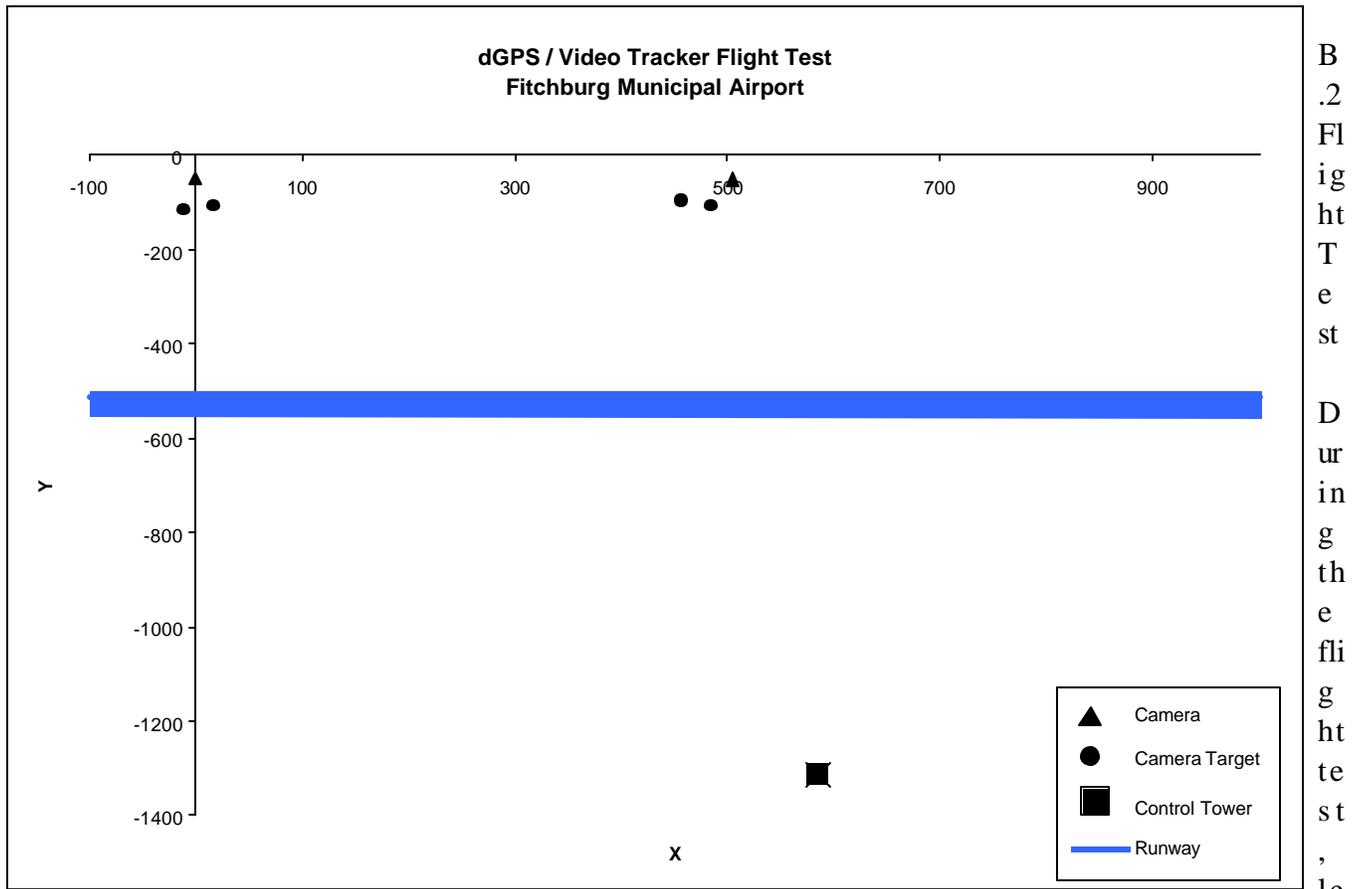
The aircraft used for the test was a Piper Aztec F (PA-23-250, tail number N327DR). A twin-engine aircraft, the Piper Aztec is a 6-passenger craft, about 31 feet nose-to-tail. The electronics for the rover system were secured in the middle row of seats on the aircraft. The GPS antenna was mounted on top of the nose of the aircraft, approximately 3.5 feet back, and the communication antenna was mounted on the belly of the aircraft, approximately 10 feet from the end of the tail. The following two figures illustrate the position of the antennae on the aircraft.





In addition to the dGPS, a digital video camera tracking system (Video Time-Space-Position-Information System: VTSPi) was used to track the aircraft. Two Canon Optura digital video cameras were placed about 400 feet southwest of Runway 32. Data taken from the two cameras were used to verify aircraft position using a triangulation technique. More detail on the VTSPi system can be found in its associated VCAF user's guide.

A local coordinate system was set up for the flight test. The origin was located approximately 560 feet south-west of Runway 32. The x-axis of the coordinate system was parallel to runway 14/32, with the coordinate system oriented per the right-hand-rule. The figure below presents a plan view of the measurement site with the coordinate system superimposed.



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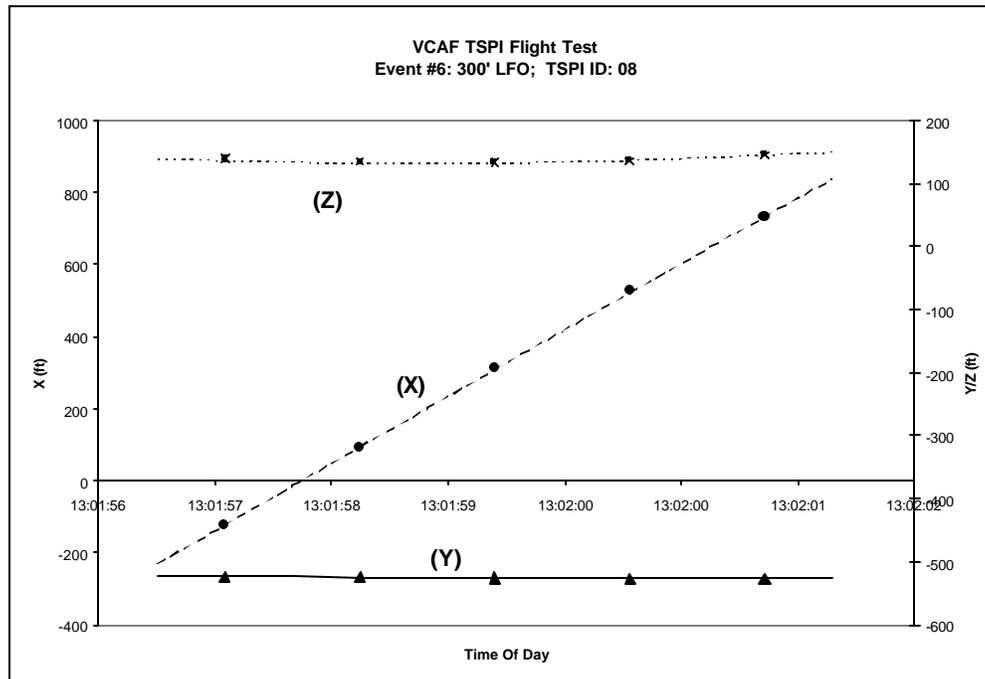
vel flyovers (LFOs), takeoffs and approaches were flown. In addition, system range tests were performed along with antenna shielding tests where the aircraft pilot made “hard” and “soft” banks to ensure the performance of the differential corrections communication data link. Two LFOs were flown at 100 ft. increments between 100 ft. and 400 ft., along with four takeoffs (2 actual and 2 “touch and go”), as well as two approaches and two system range tests in opposite compass directions.

### B.3 Results

The system proved to be extremely reliable. In general, an RT20 status of “0” was maintained throughout the tests. The RT20 status did briefly switch to “1” when the aircraft banked to return to the test area between events, and at very large distances from the airport during the system range tests (9 and 15 miles, respectively). For the periods when the RT20 status toggled to 1 due to the aircraft banking, it generally returned to 0 again within 10 to 30 seconds. However, when the status of 1 was due to the large distance from the base station, it took several minutes to return to 0.

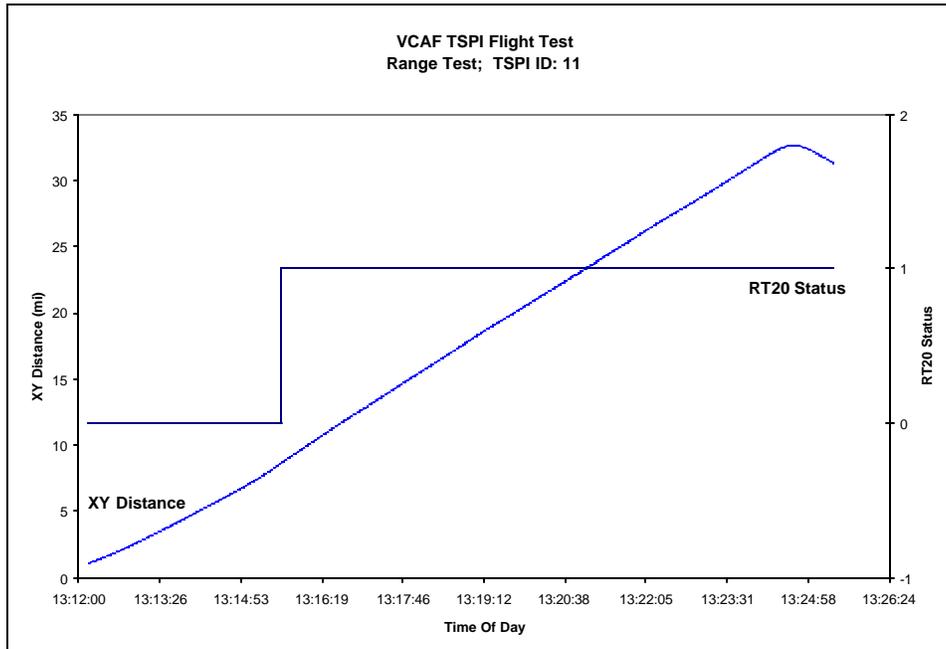
The system also proved to be very accurate. There appeared to be no data anomalies in the dGPS data. Further, when the TSPI data are compared with the VTSPI data, very good agreement is seen.

The following two diagrams present a comparison of the TSPI and VTSPI data for a single event.



T.O.D.	TSPI Data			VTSPI Data			TSPI - VTSPI		
	X	Y	Z	X	Y	Z	del X	del Y	del Z
13:01:56.5	-231.1	-522.0	138.8						
13:01:57.0	-123.0	-523.3	135.8	-123.9	-524.6	139.6	0.9	1.3	-3.8
13:01:57.5	-15.0	-524.2	133.4						
13:01:58.0	92.8	-524.9	131.6	93.3	-524.8	135.3	-0.5	-0.1	-3.6
13:01:58.5	200.5	-525.4	131.1						
13:01:59.0	307.9	-525.7	131.8	310.5	-525.9	133.4	-2.6	0.1	-1.6
13:01:59.5	414.8	-526.0	133.5						
13:02:00.0	521.2	-526.3	136.2	525.6	-526.4	135.6	-4.4	0.1	0.7
13:02:00.5	627.2	-526.6	140.3						
13:02:01.0	732.7	-526.7	144.8	733.8	-528.9	144.9	-1.1	2.1	-0.1
13:02:01.5	837.7	-527.0	148.8						

The following diagram presents XY distance and RT20 solution status versus time for the first of the two system range tests. The RT20 status for the two tests turned to a '1' at approximately 8.5 miles for the first test (to the southeast)



and 14 miles for the second (to the northwest).

#### B.4 Conclusions

The TSPI system performed both reliably and accurately throughout the flight test. As a result of the test, several minor changes are planned for the software and hardware (see Section IX, "Planned Future Enhancements to TSPI Software"), however it was determined that the system is currently flight ready.

## B.5 System Components

The following is a list of system components used during the flight test. Where appropriate, current component model numbers are highlighted after the item in “[ ]” with serial numbers in italics.

### Base Station

GPS receiver [NovAtel 3151R]	<i>CGN94340121</i>
Data-link radio [GLB SNTR 150]	<i>712136</i>
Laptop computer [IBM Thinkpad 770]	<i>78-CY580</i>
GPS antenna with choke ring [NovAtel GPS-503]	
Communication antenna [Antenex FG1360]	
9-pin to 25-pin serial cable	
9-pin to 9-pin null-modem serial cable	
TNC GPS antenna cable	
BNC communication antenna cable	
threaded rod for mounting GPS antenna	
miscellaneous clamps/adapters for mounting antennae	
Innovative International AC-to-DC converter [SB115A] (powers data-link radio off of AC current)	

### Rover

(Deployed in either a “survey” mode or on an aircraft for tracking data)

GPS receiver [NovAtel RT20E]	<i>CGK97360001</i>
Data-link radio [GLB SNTR 150]	<i>712137</i>
Laptop computer [IBM Thinkpad 770]	<i>78-CY580</i>
GPS antenna [NovAtel GPS-501 (survey mode); GPS-511 (aircraft mode)]	
Communication antenna [Dorne & Margolin C63-1/A (straight); C63-2 (bent, better clearance)]	
9-pin to 25-pin serial cable	
9-pin to 9-pin null-modem serial cable	
TNC GPS antenna cable	
BNC communication antenna cable	
miscellaneous clamps/adapters for mounting antennae	

TSPI.EXE software: Version 1.1 5/29/1999

**Appendix C:**  
**Example Analysis of Multipath Data**

A Differential Global Positioning System (dGPS) Time-Space-Position-Information TSPI system's accuracy can, under certain circumstances, be greatly compromised by the presence of multipath at the base station. Specifically, a GPS antenna may receive both a direct signal from a given GPS satellite, as well as a reflected signal (or several reflected signals), which would degrade the signal quality and possibly cause inaccurate TSPI. For all intents and purposes, multipath at the rover may be neglected.

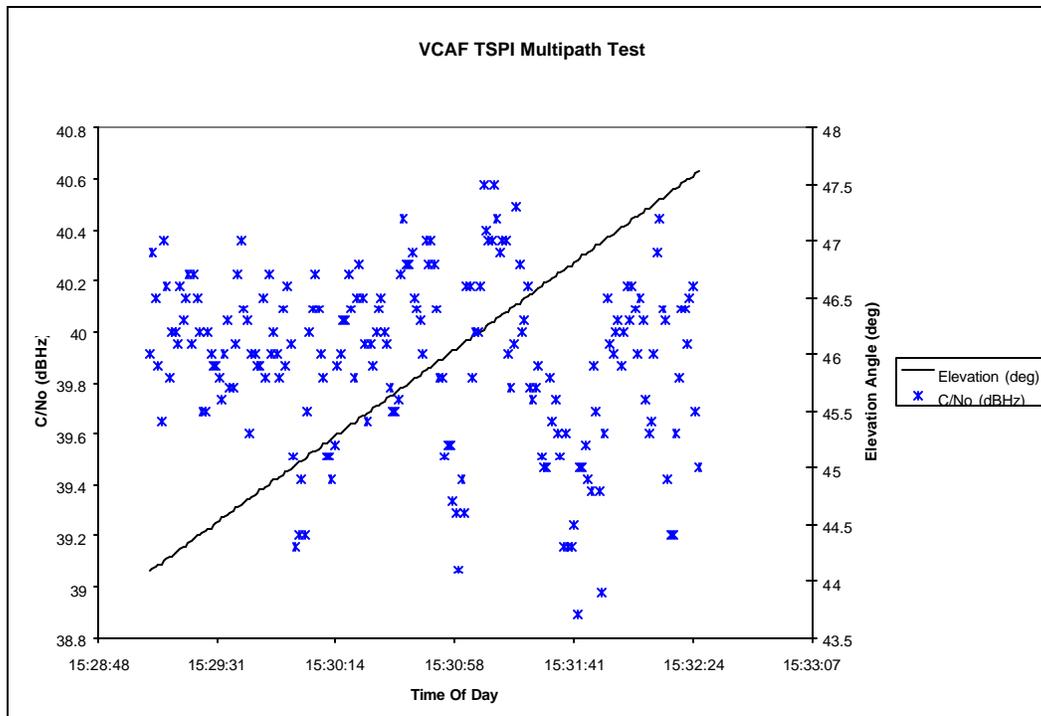
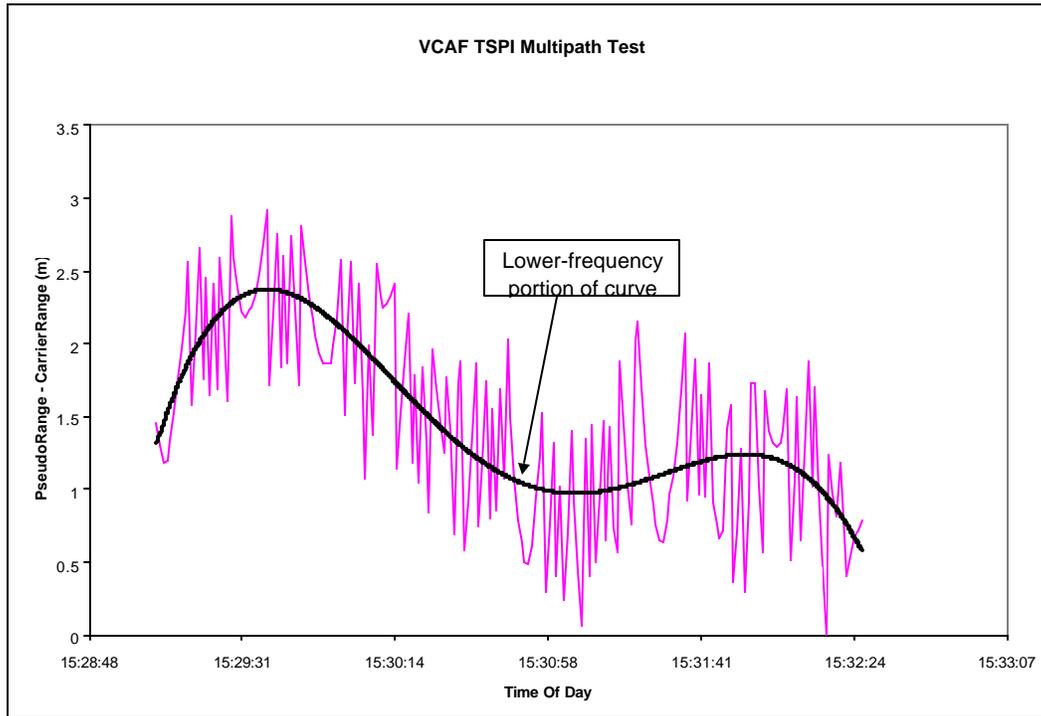
There are two general means by which a system's multipath error may be minimized: Instrumentation and Site Selection. Within the instrumentation side, there are three specific options. First, simply adding a device such as a choke ring to an antenna greatly minimizes the reception of signals originating (reflecting) below the plane of the antenna. Second, an elevation angle cutoff algorithm may be implemented in conjunction with the GPS receiver, such that only signals above that angle (with respect to the horizon) will be processed. Finally, dual-frequency receivers and antennae (L1/L2) are available which effectively eliminate multipath. Choosing the proper location of a base station GPS receiver antenna is also important for mitigating the effects of multipath. Ideally, the antenna should have a clear view of the sky down to the horizon, in all directions. There should be no large, reflective objects (i.e., buildings, bunkers, cars, etc.) within 500 to 1000 feet of the antenna. In lieu of a choke ring, or similar device to minimize ground reflection multipath, the antenna should be placed as close to ground level as possible.

Despite there being no universally accepted way of measuring/calculating multipath, there is one relatively common method used for determining whether multipath error is potentially a problem at a particular site for a given time period during the day<sup>1</sup>. After multipath data is collected at a given site, it must be analyzed on a satellite-by-satellite basis. One analysis method is to plot the difference "Pseudo Range minus Carrier Range" versus time for the time period of interest. An example of limited duration is shown on the following page. In general, the plot will appear as a slow, time-varying curve with a higher frequency "noise" component superimposed on that curve. A multipath error will likely be represented by a rise and fall (or "scalloping") of the lower-frequency curve, inconsistent with the remainder of the curve. Analyses of multipath can also be performed by examining the associated signal-to-noise (S/N) ratio as a function of elevation angle for each satellite and time. A noticeable scalloping effect coinciding with a sharp drop in S/N is an indication of multipath. From the plots for the above-discussed relationships, one can determine what periods of the day the system is vulnerable to multipath. As noted previously, this type of analysis would be required for all satellites tracked during the hours of use of the system.

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<sup>(1)</sup> "Global Positioning System: Theory and Applications, Volume 1" American Institute of Aeronautics and Astronautics, Inc., Washington, D.C.

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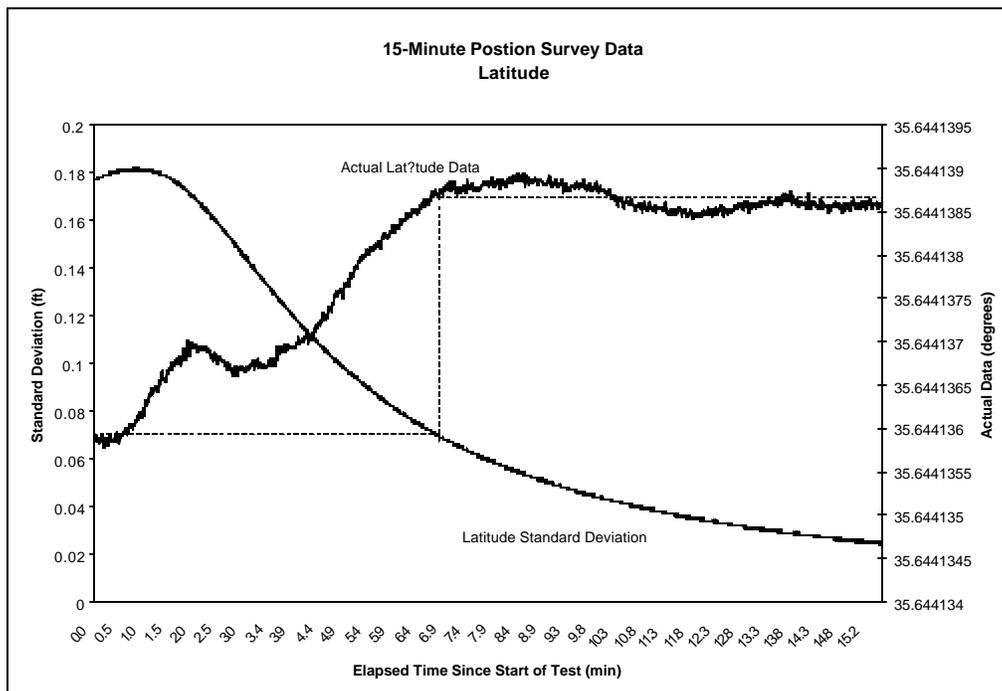


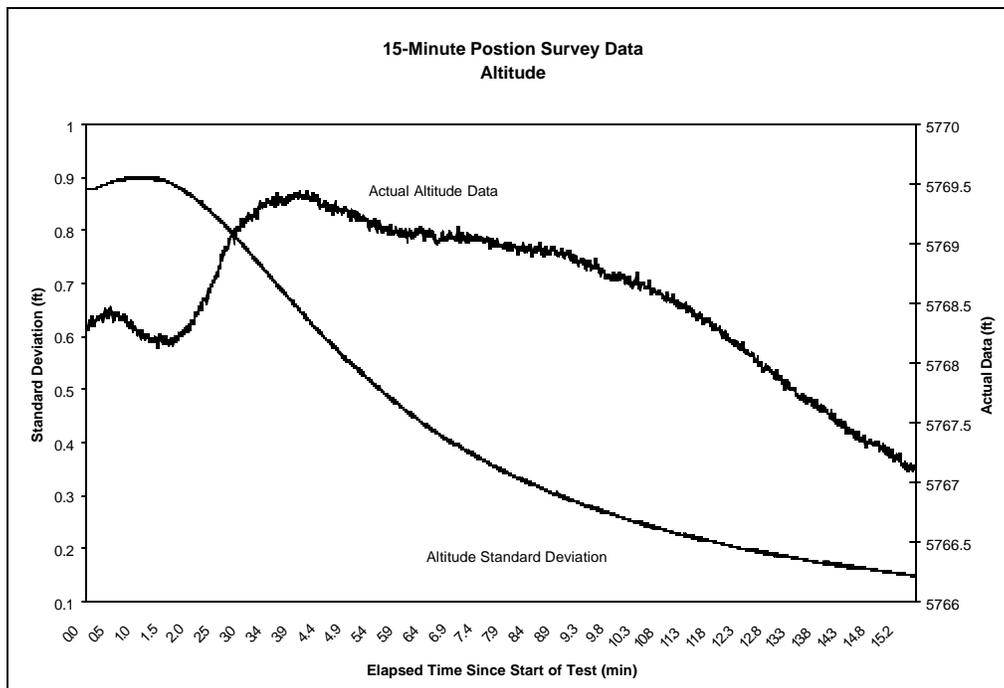
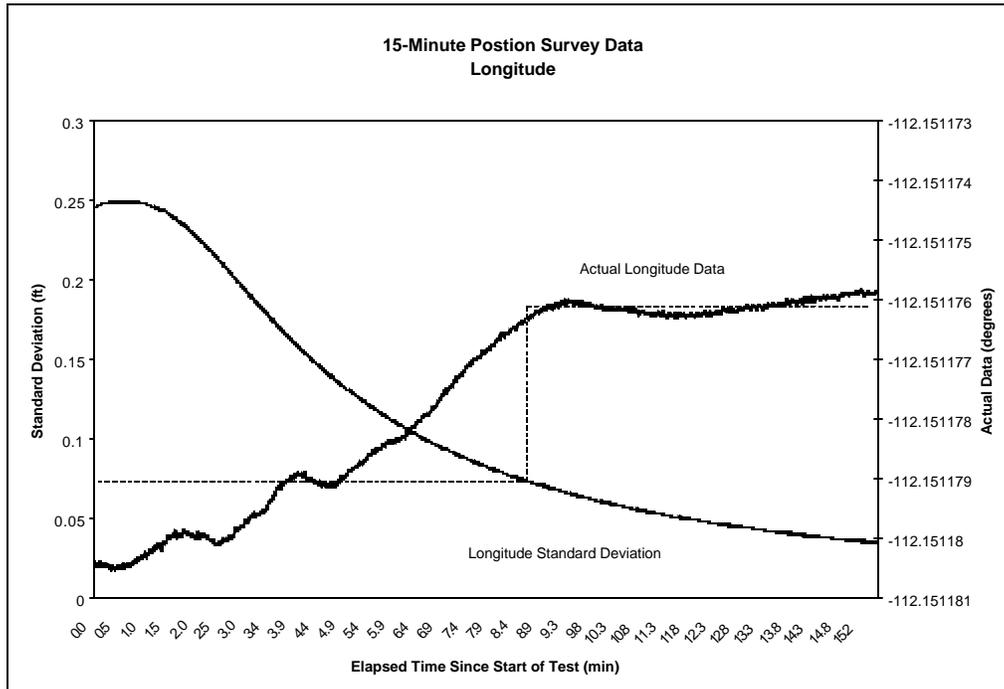


**Appendix D:**  
**System Stability Test**

During a VCAF flight test at Valle Airport, near Grand Canyon, Arizona, a brief stability test was performed on the TSPI system. With the hopes of determining exactly how long is required to collect accurate survey data at a given location, data were collected with the rover in a fixed survey position for approximately fifteen minutes. Though no multipath data were collected, it was assumed that the site did not have multipath because the terrain was extremely flat and there were no large or reflective objects within several thousand feet.

As outlined in the following three diagrams, the latitude and longitude stabilized within approximately six to nine minutes. Latitude and longitude stabilization appears to correlate to associated standard deviations of between 0.07 and 0.08 feet. The altitude data was not stabilized after the full 15 minutes, but appeared to be in the process of converging. It should be noted that the RT20 solution status was at 0 for the duration of the fifteen minute period, which per the manufacturers specifications, indicates better than 20 cm accuracy.







**Appendix E:**  
**Sample Data Logs**

Presented below are sample data logs to be used during field tests with the VCAF TSPI system. As all field tests have different data requirements, these are merely presented as examples of the type of data typically logged in the field.

**Site Survey**

Site Name: \_\_\_\_\_ (name of site)

Page  X  of  X

Data Directory: (data directory on hard drive)

Date: (mm/dd/yy)

Observer:  (name)

Time of Day	TSPI ID	File Type	RT20 Status	X	Y	Z	Comments
0700	000	SB	(NA)	-	-	-	Base Station Survey- on hangar roof
0740-50	000	SP	0	-	-	-	coordinate system points
0755	000	TP/TV	0	0	0	0	Sanity Check- centerline mic
0853	001	TP/TV	0	0	492	0.2	Sanity Check- west sideline microphone
0902	002	TP/TV	0	0	-492	-0.3	East sideline microphone
0909	003	TP/TV	0	253	178	2	meteorological station

Note: *SB*, *SP* and *TD* file designations stand for *Survey Base*, *Survey Point* and *Track Data*, respectively. Section V, Output File Formats presents the specifics related to these data files.

**Flight Test**

Site Name: \_\_\_\_\_ *(name of site)*

Page  X  of  X

Data Directory: *(data directory on hard drive)*

Date: *(mm/dd/yy)*

Observer: \_\_\_\_\_ *(name)*

<b>Time of Day</b>	<b>TSPI ID (TD)</b>	<b>Event #</b>	<b>RT20 Status</b>	<b>Event Type</b>	<b>Direction</b>	<b>Comments</b>
1030	004	01	0	500' LFO	N	altitude ~ 420'
1037	005	02	0	500' LFO	S	
1042	006	03	0	500' LFO	N	slightly to the west
1051	007	04	0	500' LFO	S	
1058	008	05	0	500' LFO	N	high altitude jet interference
1104	009	06	0	T/O	N	
1111	010	07	0	T/O	N	



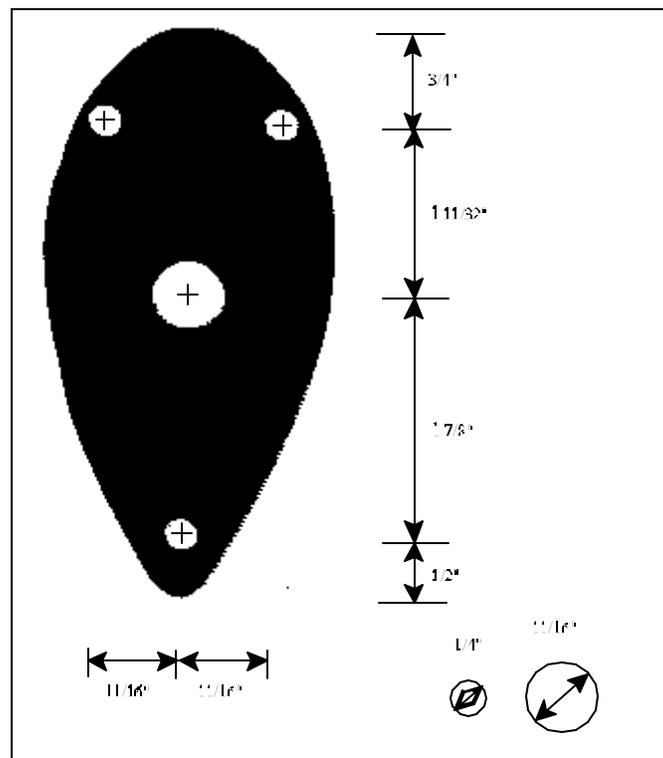
**Appendix F:**  
**Installation of Antennae on Aircraft**

The following is included as useful information for installation of the GPS and communication antennae required for use of the VCAF TSPI system.

The GPS and communication antennae need to be installed on the outside of the aircraft. The GPS antennae has to be installed on the top of the craft, clear of anything which may prevent line-of-sight to the sky (i.e., not adjacent to other large antennae or near the aircraft's tail). The data-link communication radio antenna has to be installed on the bottom of the craft, clear of anything which may prevent line-of-sight to the GPS base station on the ground.

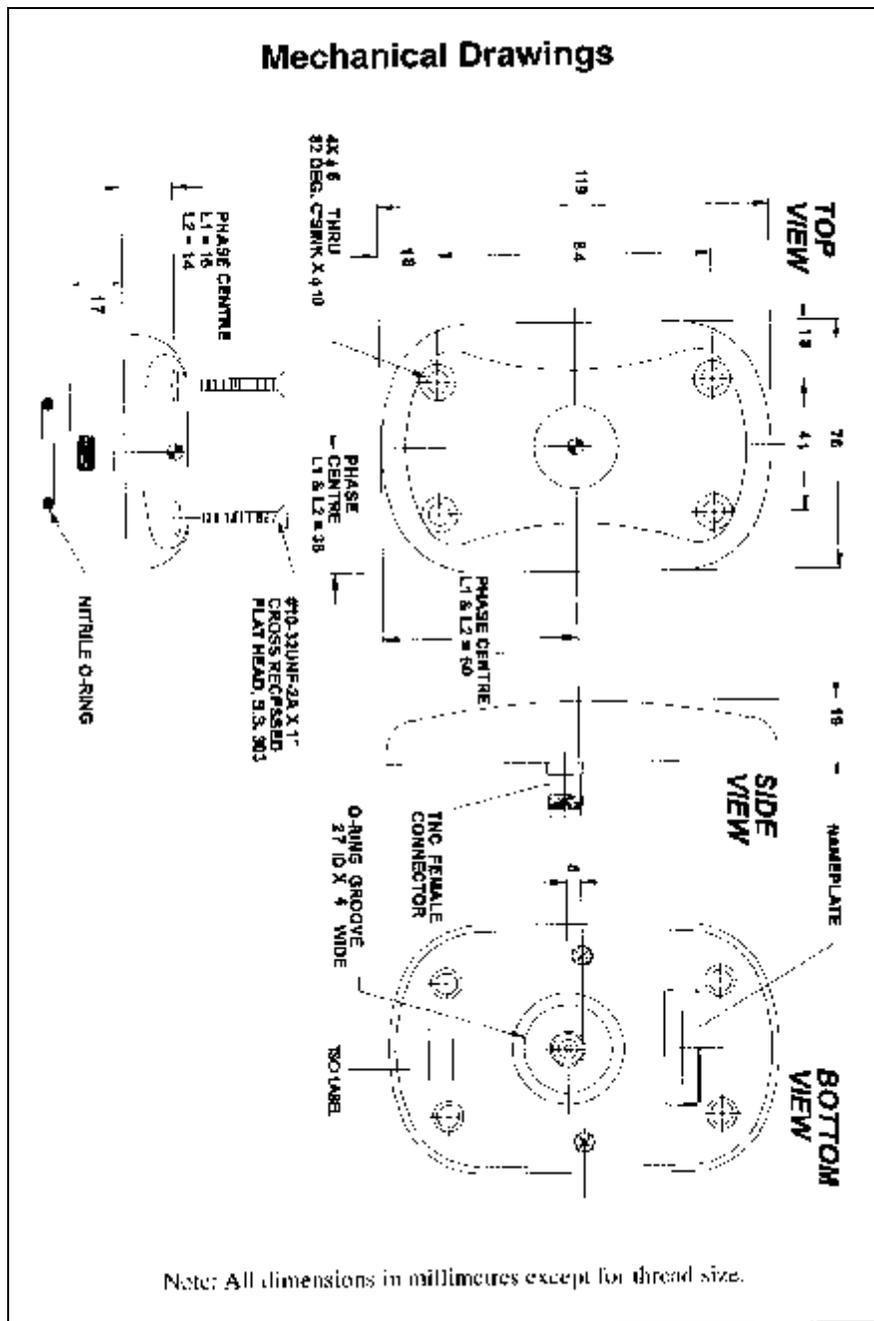
The data-link radios utilize a communication frequency of 136.325 MHz.

The GPS antenna, which has a nominal impedance of  $50\Omega$ , provides approximately 26 dB of gain to the GPS receiver. As such, it draws up to 50 mA and requires a polarization voltage of between 4.25 and 18.0 V<sub>DC</sub>. Presented below is a footprint of the radio antenna and its specifications.



The large hole in the middle of the faceplate is for the BNC cable used to connect the antenna to the radio. The three 1/4" holes are for screws used to attach the antenna to the aircraft fuselage or skin-doubler.

Presented below is a footprint of the GPS antenna and its specifications.



As with the radio antenna, the connector (TNC, male) is located at the center of the GPS antenna.